Satiation Feed Consumption as an Inventory Tool to Assess Biomass of Channel x Blue Hybrid Catfish in Earthen Ponds

by

Ricardo Arguello

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Approved by

Ronald P. Phelps, Chair, Associate Professor of Fisheries and Allied Aquacultures
William H. Daniels, Associate Professor of Fisheries and Allied Aquacultures
Donald Allen Davis, Professor of Fisheries and Allied Aquacultures

Abstract

The present study was conducted to determine the percentage body weight of feed that specific sizes of hybrid catfish consume at various water temperatures when fed to satiation under pond conditions. This information, along with the quantity of feed provided per pond, was used to estimate the fish biomass in any given pond. It was hoped that this technique would provide an economical alternative to farmers in search of better inventory assessment tools.

Hybrid catfish were stocked into 0.04 ha ponds at a density of 4,000 fish/ha, by size categories of fingerlings, stockers, food-size, and large food-size fish. Large food-size fish were stocked at a lower density of approximately 1,750 fish/ha. The fish were fed to satiation at water temperatures of about 15, 20, 25, and 30 C. Satiation estimates were obtained for each pond a minimum of three times prior the last satiation feeding. The total weight of feed consumed was calculated in two different ways. First it was determined by assuming that all of the feed was consumed. The second way used a correction factor that assumed fish only ate the feed that floated and ignored any that sank to the bottom of the pond. Forty-five minutes after the last satiation feeding the ponds were seined and a sample of 25 individuals per pond was harvested. Each fish was weighed, the stomach dissected, and the number of pellets found in the stomach counted. The number of pellets per unit weight of dry pellet feed was determined in advance, and based on the pellet count, a weight of dry pellet feed consumed was calculated and expressed as a percent body weight of feed consumed. After the last satiation feeding, any pond that was sampled was harvested and the biomass was determined after holding the fish approximately 24 hours. Fish biomass was estimated based on the average percentage of body weight consumed from the sample of 25 fish for each pond and was converted to a standing crop as kg/ha. The standing crop estimate was then compared to the actual standing crop from the day of harvest to verify the accuracy of the technique.

Results of the study suggest that both fish size and temperature had a significant effect on the percentage of body weight consumed. Overall, after applying correction factors, the technique was only effective in estimating 30.8% of the cases within 10% of the actual standing crop. However, when fish were feeding actively and consistently (such as the stockers at 25 and 30 C) the estimated standing crops were within 10% of the actual standing crops on 75% of occasions. Nevertheless, in most circumstances the use of satiation feed consumption is not an effective tool for estimating fish biomass.

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I. INTRODUCTION

Aquaculture in the United States is dominated by the culture of catfish, which yields over 50% of all aquaculture production in the nation (USDA 2007). Catfish farming and allied industries such as processing plants and feed manufacturers are valued to be over seven billion dollars (USDA 2007). In Alabama in 2006, the catfish industry generated about 2,700 jobs and was valued at more than $105 million (Crews and Chappell 2007). In addition, $90 million in sales were generated by associated enterprises (Crews and Chappell 2007). Over the past few years, the growth of the industry has significantly declined due to increased costs and heightened competition from foreign markets. However, the value of domestic production of catfish actually increased by 8% from 373 million dollars to 403 million dollars from 2009 to 2010 (USDA 2011). The catfish industry utilized 40.3 thousand hectares (99.6 thousand acres) in terms of surface area (of water) since the beginning of January 2011 (USDA 2011). This was 13% lower than the prior year (USDA 2011). The reduced surface area is a reflection of a shrinking industry primarily due to increased costs, which can be linked to higher feed costs.

In 2008 catfish feed prices increased to over $363 per metric ton (over $400 a ton) which was substantially higher than the $227 per metric ton ($250 a ton) that was previously paid (Coblentz 2008). Feed accounts for 50% of all production costs (Coblentz 2008); so, any minor improvements in feed conversion can greatly enhance profitability. Poor feed conversions can occur when biomass or the population structure is overestimated. An overestimate of biomass is often a result of incorrectly assessing the rate of mortality and/or growth. When mortalities are underestimated, biomass may be overrepresented resulting in excessive feeding and a higher feed conversion. This was evident in Park (1989) where fatalities were misjudged in ponds containing young channel catfish. Differences in feed consumption by various sizes of fish held in the same pond can also result in inaccurate estimates of biomass. Larger fish generally have a less efficient feed conversion than smaller fish (Robinson et al. 1998), so if the abundance of large fish in a pond is underestimated, then productivity is reduced. In addition, if mixed sizes of fish are in the same pond, competition may occur leading to the exclusion of smaller fish from obtaining feed in a timely manner (Randolph and Clemens 1976). Accurate estimates of biomass in ponds are essential for improving feed conversion and, therefore, enhance the economic efficiency of the entire aquaculture operation.

Accurate estimates of inventory are critical for a variety of reasons. For instance, they are necessary for acquiring bank loans or crop insurance. Processing plants need to obtain specific fish sizes and quantities in order to efficiently operate each day. Producers often make arrangements with a processing plant before any of the fish are harvested and provide estimates with regard to size distribution and total quantity of fish available to be harvested. However, once the fish were harvested, the producer often realizes that the estimates of biomass and size distribution were incorrect resulting in the processing plant paying the producer less than anticipated. The lack of fish in the needed quantity and size also increases the costs to the processor making it more difficult for the U.S. catfish industry to remain competitive on the global market place. Having an accurate estimate of biomass and size distribution is critical for efficiently running any aquaculture operation and is essential for providing optimum return on the investment.

Keeping accurate inventories for catfish in ponds, as well as many other aquatic organisms, is extremely difficult due to the reduced visibility of the aquatic environment (Killian et al. 1998). Once the fish are stocked into ponds, the producer can no longer observe all the fish making it difficult to quantify them or to observe health status, mortality, or growth. Frequent sampling of the population can aid in monitoring growth but the sampling techniques usually stress the fish and increase the risk of disease (Rottmann et al. 1992), which may eventually lead to a depression in feed intake. Passive techniques to determine biomass and size distribution are necessary in order to ensure optimum production of the fish crop.

In the United States, the most common method of commercial catfish production is a multiple-batch system (Tucker et al. 2004). This system contains various size categories of fish ranging from fingerling to large market size in any given pond at any given period throughout the year. The water in the ponds is retained and never completely discharged under this culture system. As the demand for food fish arises, the larger fish are harvested with a seine made up of a large mesh size, which allows the smaller fish to escape and grow until they reach a suitable size for market. The ponds are then stocked with small fish to replace the larger fish that were harvested. Once a multiple-batch pond has been in production over several years, it becomes extremely difficult to know fish abundance in the ponds due to the variability in fish size distributions (Tucker et al. 2004).

Multiple-batch systems are extremely effective in providing cash flow as a segment of the population will be market-size and can be sold at any point during the year (Tucker et al. 2004). It is an economically feasible production choice but can be made more profitable by better knowing fish size distribution and total biomass. However, the catfish industry in the U.S. is capable of providing fish year round with a single-batch system, when accounting for economies of scale, but nevertheless, the multiple-batch system still remains prevalent (Hargreaves and Tucker 2003). Having enough ponds in production using a multi-batch approach helps ensure that healthy, on-flavor, marketable size fish are available throughout the year (Tucker et al. 2004). If the pond is found to be off flavor in a single-batch system, the availability of that size class for the market is reduced. Fish are therefore hindered from reaching the market place and less market fish may be available at a given point in time. However, with the multiple batch system, each pond contains various size classes so if fish in one pond are off-flavor or diseased, the likelihood of the other ponds containing the various size classes needed to meet year round demand is much higher. The multiple batch system is also heavily favored since ponds are in production over a period of several years, which saves water, reduces possible pumping expenses, and diminishes the quantity of waste matter released into the environment (Hargreaves and Tucker 2003).

The overarching goal of the study was to develop an effective and economical inventory assessment technique based on feed response, to determine biomass of hybrid catfish in earthen ponds. To do so, the percentage body weight of feed that specific sizes of hybrid catfish could consume at different water temperatures was assessed. That estimate allowed biomass to be extrapolated based on the quantity of feed fed. By knowing the quantity of feed consumed when fish of a given size category at a given temperature were fed to satiation, it was hoped that a more realistic estimate of biomass could be made when multiple sizes of fish were cultured in the same pond.

II. LITERATURE REVIEW

Culture characteristics of hybrid catfish (*Ictalurus punctatus* x *I. furcatus*)

It has been reported that the hybrid catfish possesses numerous favorable production traits when compared to channel catfish (*Ictalurus punctatus)*. Ligeon et al. (2004) found that hybrid catfish culture was more economical than that of channel catfish. They determined that there was a 15.0-22.5% reduction in mean overall cost of hybrid catfish fingerling production, when compared to channel catfish. One advantage of using hybrids is that they exhibit increased tolerance to low dissolved oxygen levels when compared to channel catfish. Evidence of this claim is addressed by Dunham et al. (1983) who found that hybrids exhibited enhanced survival over channel catfish when subjected to low dissolved oxygen levels while in concrete tanks, cages, and ponds. Mortality rates for oxygen-deprived ponds, brought about by the application of formalin, were about 50.5% for the channel catfish and 7.5% for the hybrids. Likewise, about 87.5% of channel catfish and 51.0% of hybrids perished when the fish were reared in cages. Survival in the concrete tanks was 0% for the channel catfish and 67% for the hybrids.

In terms of survival rates, it has often been reported that hybrid catfish generally outcompete channel catfish. Li et al. (2004) found that hybrid catfish survival was greater than that of the NWAC 103 channel catfish (93.8% vs. 85.4%) when placed into ponds at a density of 14,820 fish/ha. Furthermore, Wagner (1998) found that channel catfish exhibited an inferior survival rate when compared to the hybrids (68.5 % vs.

92.5%) as they were subjected to different winter feeding schedules and fed ad libitum in the spring. However, the lower survival in the channel catfish may have been the result of detrimental parasitic activity possibly due to various stressors at the time of stocking. Dunham et al. (1990) also found that hybrid fry survival in ponds was greater than that of the channel catfish when they were distributed separately at densities of 741,000 fry/ha (100% vs. 29.5% survival). This high mortality in the channel catfish may have been due to the harmful effects of *Flexibacter columnaris.*

Wolters et al. (1996) found that hybrid catfish and channel catfish had survival rates of 73.8 ± 6.7% and 62.0 ± 4.2%, respectively, when subjected to an immersion bath with *Edwardsiella ictaluri*. When injections of *E. ictaluri* were given, only the channel catfish exhibited significant fatalities. Truong (2011) found that channel catfish were susceptible to the infection of 14 species of metazoan parasites, while hybrid catfish were susceptible to 12 species and blue catfish were susceptible to only seven species.

Yant et al. (1975) found that survival of channels and hybrids was not statistically different when they were cultured in ponds. Survival for both channels and hybrids was about 99%. The channel catfish in the study had a mean weight of 22.9 kg/1,000 (50.6 lbs/1,000) and the hybrids were about 22.8 kg/1,000 (50.3 lbs/l,000). The fish were reared for 220 days. Both channel and hybrid catfish were distributed into six ponds (three ponds for each species) at 7,413/ha (3,000/acre) and another pond contained a mixture of both channels and hybrids at a rate of 2,471/ha (1,000/acre) for each type of fish. Likewise, Jiang (2005) determined that average survival (mean ± standard error as obtained directly from Table 5 in his study) was 93.7 ± 0.8% for HS-5 channel catfish, 77.9 ± 7.9% for NWAC 103 channel catfish, 93.4 ± 0.7% for NWAC 103 channel x

D&B blue catfish, 88.1 ± 2.1% for D&B blue catfish, and 91.4 ± 4.3% for HS-5 channel x D&B blue catfish.

Hybrids display growth that is more uniform than channel catfish. Yant et al. (1975) determined that when fish were harvested the channel catfish were less uniform in length than the hybrids. At the end of the study, fish were divided into groups by inches (1 inch= 2.54 cm). Three principle size classes were identified: 35.6 cm (14 inches), 38.1 cm (15 inches), and 40.6 cm (16 inches). Seventy-six percent of the channels could be categorized into these size classes as opposed to 87% of the hybrids. Brooks et al. (1982) found that the hybrids reared to 150 mm were less variable in size than channel catfish. Giudice (1966) found that the hybrid catfish were more uniform in terms of weight (CV of 22% for the channels vs. 17% for the hybrid catfish) when both channel and hybrids were cultured together in ponds.

Hybrid catfish are also known to have a better dress-out percentage than channel catfish. Argue (2003) found that the channel x blue hybrid (F_1) had a dress-out percentage of 61.1% while the channel catfish had a dress-out percentage of 57.5%. Yant et al. (1975) determined that channels yielded a lower mean dress-out percentage of 61.2% as opposed to the improved 64.5% of the hybrids. Likewise, Argue (2003) found that the channel x blue hybrid (F_1) had a fillet percentage of 45.7% while channel catfish had a fillet percentage of 42.5%.

Hybrid catfish have been reported to have better feed conversion ratios (FCRs) than channel catfish in some studies. Chappell (1979) found that the mean FCR of the channel x blue hybrids (1.21) was statistically better than the mean FCR of its maternal and paternal species when 12 genetic classes of catfish were compared in earthen ponds.

Yant et al. (1975) determined that the average FCR for hybrids was 1.35 while channel catfish had an average of 1.56 when fish were cultured in ponds. However, Jiang et al. (2008) found that there was no significant difference in average FCR between channel and hybrid catfishes when they were reared in earthen ponds.

Hybrid catfish have been reported to differ in their ease of seining in comparison to channel catfish. Yant et al. (1975) found that it only took one seine haul to harvest 75% of the hybrids in the ponds. However, they found that to harvest the same amount of channel catfish in the ponds, a minimum of two seine hauls were necessary. Chappell (1979) also found that channel x blue hybrids and blue catfish were less difficult to seine than the channel catfish. For instance, 64.6% of the channel x blue hybrid population was captured while only 18.5% of Auburn strain channel catfish and 24.3% of Kansas strain channel catfish were harvested when the average percentage of fish captured per seine haul during the summer was calculated.

Susceptibility to angling is another key feature of the hybrids, which may be quite beneficial with respect to a fee fishing enterprise. Tave et al. (1981) determined that hybrid catfish were more vulnerable to capture by angling than channel or blue catfish when stocked together in communal ponds. The channel female x blue male hybrid in the study represented 29.5% of the fish in the pond by number and 37.4% in terms of weight. When catchability was assessed, the channel female x blue male hybrid in the study made up 57.3% of fish captured by number and 63.8% of the fish captured in terms of weight. The parent fish (channel catfish and blue catfish) represented 41.8% of fish in the pond by number and 37.8% by weight. When catchability was assessed, the parental fish in the study comprised 25.3% of the fish captured by number and 18.8% of the weight captured.

Dunham et al. (1986) also found that the channel x blue hybrids were more easily caught by hook and line when compared to various genetic lines of channel catfish. However, they also found that the Marion x Kansas channel catfish were as susceptible (or even more susceptible) to fishing when compared to channel x blue hybrids in ponds

Hybrid catfish are known for exhibiting superior growth over channel catfish. Guidice (1966) found that when channel and hybrid catfish were cultured under communal pond conditions, the hybrid catfish yielded a higher net increase in weight (41% higher) when compared to the channel catfish. Dunham and Brummett (1999) found that hybrids had more favorable relative growth rates than channel catfish when raised under communal pond conditions, with hybrid catfish growing 35% more rapidly when evaluated against the Auburn University Kansas genetic strain of channel catfish. Dunham et al. (1990) observed that growth in hybrid catfish fry was more rapid than channel catfish when they were stocked at 98,800 fish/ha and 2,245,000/ha in communal ponds. However, channel catfish exhibited growth that was more rapid than that of the hybrids when the fry of both fish types were cultured together at a reduced stocking rate (14,820 fish/ha) in ponds during the 74 days of the study. It was also noted that at the increased stocking rates channel catfish were infected with *Flexibacter columnaris*, which may have contributed to their reduced growth. Dunham et al. (1987) observed that channel catfish exhibited growth that was significantly higher than that of the hybrids in the first experimental period, but in the second season (when fingerlings were reared to market size fish) hybrids yielded faster growth. Dunham et al. (1990) observed that channel catfish grew significantly more rapidly than the hybrids when the fish were reared in cages instead of ponds.

Methods for assessing inventory

Knowing fish size distribution and abundance are often necessary for a successful aquaculture operation. It is important to know the total biomass of fish in a pond if a calculated ration is to be provided. Likewise, it is important to know size distribution in a pond in order to estimate the fraction of market size fish available for sale in a given pond or to verify whether the fish are growing optimally. Size distribution can be reasonably estimated by means of sampling. Fish sizes from one sampling period to another can be compared to assess growth. However, frequent sampling may stress the fish resulting in increased incidence of diseases (Rottmann et al. 1992), and a depression in feed consumption. Likewise, repeated sampling may not be appropriate on a commercial operation since it may be challenging to obtain a sample that accurately reflects the size distribution of the population and repeated sampling also requires a large investment in labor.

In addition to size distribution, it is essential to have an accurate estimate of fish abundance. One method of assessing inventory is by using records from previous production periods as is described in Killian et al. (1998) and reviewed below. Previous records of production and survival can be used to estimate inventories in terms of weight or number of fish if the new crop is managed similarly to the previous crops. Prior feeding records and records of production obtained can be used to determine feed conversion at the pond level. Using that estimate of feed conversion and the total quantity of feed given to a new crop of fish, it should be possible to estimate the amount of fish biomass increase throughout the period. Mortality approximations can also be projected based on previous records. By factoring in the biomass of fish distributed into ponds and harvested, in addition to biomass increase and survival, the total final biomass of a pond can be approximated. When estimating inventory in terms of number of fish in a pond, it is necessary to know the number of fish put into the pond, the number of fish taken out of the pond, and the survival from the records.

One of the problems with using historical records to estimate inventory is that it makes the assumption that mortality will stay constant from one production period to the next. Of course, in reality survival can vary substantially among different production cycles. Mortality rates can also be problematic especially if they are obtained simply by counting the number of dead fish at the edge of the pond. Tucker et al. (1993) noted that apparent fish mortality in ponds was only 3% while in reality at the time of harvest it was 21% when fish were stocked at a rate of 19,770 fish/ha in multiple-batch ponds for three-years. Fish mortality at the ponds was examined each day as of April-November but from December-March ponds were checked on week-to-week basis. Likewise, Park (1989) found that the apparent mortality rate of fish that were collected from 0.04-ha ponds (initially stocked with channel catfish fry) represented 34.0-48.6% of actual fatalities.

Another problem with using historical records to assess inventory is that the FCR corresponds to a mean value over the whole culture period. If the FCR at the end of a prior culture period is utilized, growth may be undervalued prematurely, thus under representing pond biomass. This is due to the fact that small fish have a more efficient feed conversion than larger fish (Robinson et al. 1998), and that feed conversion is not additive as it is weighed by the quantity of feed fed hence a simple average is inappropriate. If FCR is averaged, this results in an overestimation on small fish and an underestimation of large fish. Often in a multiple-batch system some of the larger fish evade seining. Over time, the fraction of larger fish in a multiple batch system becomes greater thus reducing optimal potential productivity.

Attempts have been made for a more direct estimate of biomass. The use of side-scan sonar has been evaluated for its application in pond aquaculture. However, at the present time this does not seem to be an economical tool to estimate biomass on a commercial scale. The device has produced estimates generally within 20% of the actual biomass as revealed via the producer (USDA 2008). Another tool for estimating fish inventory is through the use of computer software such as FISHY from Mississippi State University, which relies on a number of conversions and precise data such as fish stocking, feed offerings, and harvesting which are input by the user (Killian et al. 1998). Variability in FCRs and inaccurate estimates of mortality impact the accuracy of such models to predict biomass or fish size distribution (Killian et al. 1998).

A depletion technique has also been developed to assess fish biomass in both experimental and commercial channel catfish ponds (Engle et al. 1998). In this study a seine was passed through each pond (at least three hauls per pond) in order to collect fish so a number and weight could be assessed. The fish from each seining period were taken out of the pond and the left over biomass was determined by means of a mathematical depletion model. This biomass estimate was then compared to the actual biomass of the pond (after a total harvest of the pond) to evaluate the accuracy of the technique. The depletion technique uses a model in which "the number of fish caught per unit of effort during some time interval, *t*, is proportional to the number of fish present at the beginning of the interval" (Van den Avyle and Hayward 1999). This technique also requires the following assumptions "(1) all members of the target population are equally vulnerable to capture, (2) vulnerability to capture is constant over time, and (3) there are no additions to the population or losses other than those due to fishing during the study interval." (Van den Avyle and Hayward 1999).

Results of the experimental pond research revealed that the estimated fish weights varied when compared to the actual fish weights by -0.1%, 0%, and -7.7% (Engle et al. 1998). Results from the commercial pond component of the experiment revealed that the estimated fish weights varied when compared to the actual fish weights by -3.5% to -6.1% for two ponds in 1995 and varied by -28.4 to 33.3% for 17 ponds in 1996. For the 17 ponds in 1996, 59% of the estimates were ± 10% of the actual fish weight while 82% of the estimates were ± 15% of the actual fish weight.

One promising tool for inventory assessment is the use of satiation feeding. This technique estimates biomass by dividing the amount of feed provided at satiation by the average percent body weight consumed by fish of a specific size class at a specific temperature. According to Jobling (1994) satiation feeding is defined as "the maximum amount of food a fish will consume." Satiation can also be referred to as "feeding the fish all they will ingest in a reasonable period of time" (Robinson et al. 1998). Feeding fish to satiation has the advantage of allowing all fish, including the smaller fish who are not as competitive, greater access to the diet being distributed. In addition, feeding fish to satiation is necessary when they are not consistently provided feed on a day-to-day feeding schedule (Robinson et al. 1998).

Satiation feeding has the potential to successfully assess biomass only if size variation in the population can accurately be described. The reliability of this technique also heavily depends on the effect of various environmental and biological parameters. Variation in any of those variables can hamper the accuracy of this inventory assessment method.

Environmental factors affecting feed consumption

Ammonia

High ammonia levels can have a significant detrimental impact on feed intake. Ammonia is often reported as total ammonia nitrogen (TAN), which is made up of an ionized form (NH_4^+) and an unionized form (NH_3) in a pond. The toxic form of concern in aquaculture is usually the unionized form (NH_3). The quantity of ionized or unionized forms of ammonia in the water is directly related to temperature and pH of a pond. When levels of the unionized form are high in a pond, the removal of ammonia by the fish is substantially hindered leading to physiological impairment (Boyd 1990).

Robinette (1976) determined the impact of various concentrations of ammonia on feed consumption in small channel catfish reared in fiberglass tanks at mean water temperatures of about 23.0, 25.3, 25.1, and 25.8 for experiments 1, 2, 3, and 4 respectively. The mean unionized ammonia levels used in the study were 0.01, 0.06, 0.12, and 0.13 mg/L. Feed consumption at the different ammonia concentrations was compared against a control group, which was generally on average 0.001 mg/L or lower for each experiment. The study found that feed consumption for the higher ammonia concentrations (0.12 mg/L and 0.13 mg/L) was lower than that of the control. At 0.12 mg/L unionized ammonia, the fish consumed 25.1 pellets/fish while the control consumed 75.3 pellets/fish. At 0.13 mg/L unionized ammonia, the fish consumed 21.1 pellets/fish while the control consumed 54.9 pellets/fish.

Knepp and Arkin (1973) performed an experiment that investigated the level of ammonia it would take to kill 50% and 100% of 10.2-15.2 cm (4-6 inch) channel catfish stocked into 28.4 L (7.5 gallon) glass bowls. Of particular interest was that this study documented at which total ammonia level fish stopped feeding. The glass bowls had air stones, a fiber filter , and the pH was held at 7.2 to 8.2. Results of the study showed that fish discontinued feeding when total ammonia was about 30 mg/L. Fifty percent of the fish perished when the total ammonia concentration was about 37.5 ± 1.7 mg/L while approximately 100% of the fish were dead at an average concentration of 45.7 ± 6.0 mg/L. About one week was necessary for total ammonia levels to yield 50% mortality from a concentration of 1 mg/L. It generally took about one day after arriving at 50% mortality for 100% mortality to occur.

Arana (1999) evaluated how feed consumption was influenced by different ammonia, dissolved oxygen, and nitrite levels in 400-468 g channel catfish distributed at 4,500 kg/ha in 20 m^2 tanks. The elevated ammonia group was designated for tanks where unionized ammonia was kept over 0.11 mg/L during the afternoon and the reduced ammonia group was designated for tanks where unionized ammonia was kept under 0.11 mg/L during the afternoon. Fish were fed ad libitum on a day-to-day basis and feed consumption was conveyed as % body weight/d. The average temperature in the tanks in experiment I was 30.3 ± 1.8 C and 27.3 ± 0.5 C in experiment II. The average unionized ammonia value during the afternoon for the reduced ammonia group was 0.04 mg/L while the value was 0.50 mg/L for the elevated ammonia group in experiment I. The average unionized ammonia value during the afternoon for the reduced ammonia group was 0.04 mg/L while the value was 0.86 mg/L for the elevated ammonia tanks in experiment II. The study found that in the elevated dissolved oxygen group, average feed consumption was not significantly different between the elevated and reduced ammonia treatments (1.81 ± 0.47 % vs. 1.77 ± 0.12 body weight/d respectively). However, for the reduced dissolved oxygen tanks, feed consumption was significantly higher in the reduced ammonia group than in the elevated ammonia group (1.38 ± 0.41 vs. 0.56 ± 0.27 % body weight/d respectively).

Dissolved oxygen

Dissolved oxygen (DO) concentrations in the water have a considerable effect on feed consumption in catfish. Buentello et al. (2000) found that when percent oxygen saturation decreased from 100% to 30%, feed consumption gradually diminished in channel catfish. The study examined the impact of dissolved oxygen levels at 30, 70, and 100% saturation as well as the influence of temperature on feed consumption in young channel catfish reared in aquaria. They found that dissolved oxygen levels under about 70% air saturation substantially decreased feed consumption in channel catfish. In addition, they found that under 70% saturation, the impact of temperature on feed consumption did not appear to be as strong as the higher DOs.

Andrews et al. (1973) determined the impact of DO concentrations of 36, 60, and 100% saturation on feed consumption in fingerling channel catfish (60 g mean initial weight). The fish were reared in fiberglass tanks and fed each day to satiation or at 3% of the fish biomass. Fish were held at a water temperature of 26.6 ± 0.1 C. Results of the experiment indicated that different dissolved oxygen concentrations had a considerable impact on feed consumption. They found that when fish were fed to satiation, they ate 2.1% of the fish biomass at 36% saturation, 2.9% biomass at 60% saturation, and 3.3%

biomass each day at 100% saturation.

Torrans (2005) conducted an experiment to see how different minimum DO levels each day influenced feed intake. The fish used in the study were channel catfish that were were stocked into 0.1 ha ponds. For the 2002 portion of the study, the ponds with elevated oxygen levels had aerators turned on when DO levels were under approximately 5.0 mg/L. For the ponds with reduced oxygen levels in 2002, aerators were turned on when DO levels were under about 1.5 mg/L. As of July-September 2002, mean feed intake in the ponds with elevated oxygen concentrations was greater than those with reduced oxygen levels. The entire feed intake in the ponds with elevated oxygen concentrations was 42,331 kg/ha while in the ponds with reduced oxygen levels it was 23,247 kg/ha.

Photoperiod

Several studies have evaluated the effect of photoperiod on fish. Ergün et al. (2003) conducted a study using fingerling rainbow trout (*Oncorhynchus mykiss*) held in a flow-through system and were fed ad libitum under various photoperiods over 60 days. The experiment studied the influence of a photoperiod of 24 light hours : 0 dark hours, a photoperiod of 16 light hours : 8 dark hours, and a natural photoperiod on fish feed consumption. They found that feed consumption in the 24 light hours : 0 dark hours photoperiod and the 16 light hours : 8 dark hours photoperiod was statistically greater than feed consumption in the natural photoperiod . Petit et al. (2003) compared feed consumption in 3.5 g largemouth bass (*Micropterus salmoides*) stocked in aquaria when assigned to a photoperiod of 12 light hours : 12 dark hours and a photoperiod of 24 light hours : 0 dark hours for 12 weeks. The results revealed fish exposed to the photoperiod of

24 hours of light : 0 hours of dark had a higher feed intake than the fish designated to the 12 light hours : 12 dark hour photoperiod. Danışman-Yağcı and Yiğit (2009) examined the impact of photoperiod on feed consumption in mirror carp (*Cyprinus carpio*) cultured in polypropylene tanks for 90 days. Fish in the experiment were stocked at a weight of 6.14 ± 0.01 g and were subjected to photoperiods of 12 hours light : 12 hours dark, 16 hours light : 8 hours dark, and 24 hours light : 0 hours dark. Feed consumption was not statistically different among the three photoperiods used in the experiment.

Jonassen et al. (2000) studied the impact of photoperiod and temperature on feed consumption in Atlantic halibut (*Hippoglossus hippoglossus* L.) stocked at 11.6 g in tanks. They used a natural photoperiod as well as a photoperiod that continuously exposed the fish to light. The results of the experiment revealed that photoperiod appeared to have no impact on feed consumption. However, temperature significantly influenced feed consumption. Kilambi et al. (1970) assessed how different light regimes and temperature affected feeding in channel catfish stocked at a size of 21.4 mm in tanks. Fish were subjected to temperatures of 32, 28, and 26 C and exposed to two light regimes :14 h of light and 10 h of light. Results indicated that feed intake was greater during the 10 h light regime (in contrast to the 14 h light period) at 32 and 28 C over the 120 days of the experiment.

<u>Temperature</u>

As the majority of fish are poikilotherm animals, water temperature controls the rate of most metabolic processes including feed consumption. Several studies have documented the effect of water temperature on feed consumption in catfish. Buentello et al. (2000) found that feed consumption by channel catfish stocked at 15.0 ± 0.23 g in aquaria at different dissolved oxygen concentrations, increased when water temperature was elevated from 15.7 to 31.7 C. They also found that feed consumption was suppressed the most at 15.7 C. Feed consumption was greatest relative to all other temperature and dissolved oxygen groupings when fish were exposed to a temperature and DO of 30 C and 100% saturation in the spring.

Li et al. (2008) observed that feed intake differed among channel catfish placed in tanks over a nine-week period at temperatures of about 27, 21, and 17 C. At the beginning of the study the channel catfish weighed 9.6 ± 0.1 g. Feed with various concentrations of fishmeal was also provided to the fish in the study. Feed intake was reported as 90% dry matter. On average, fish consumed 13.4 g/fish at 17 C, 41.4g/fish at 21 C, and 120 g/fish at 27 C.

Wagner (1998) found that when channel catfish were fed to satiation they ate 2.37% body weight per day between 23 to 27 C while they only ate 0.7% body weight per day at pond temperatures between 15 and 18 C. Channel catfish were stocked at a mean weight of 92 g and harvested at a mean ending weight of 207 g. Likewise, he also found that when hybrid catfish were fed to satiation, they ate 3.18% body weight per day at temperatures between 23 to 27 C, while they only ate 0.38% body weight per day at pond temperatures between 15 and 18 C. Hybrid catfish were stocked at a mean initial weight of 95 g and harvested at a mean ending weight of 212 g.

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Kubaryk (1978) found that feed consumption decreased in channel catfish at the end of the study when pond temperatures were lower. The experiment evaluated the relationship between feed intake and "how often fish were fed" in channel catfish with an initial mean weight of 83 g reared over 16 weeks. Fish were placed into ponds at a rate of 5,000 fish/ha and fed ad libitum for 45 minutes. Once pond temperatures were 26 C or higher early in the day, the treatment in which fish were provided feed two times a day yielded the greatest feed consumption. When the pond temperatures were under 26 C early in the day, feed consumption was substantially reduced. It was also mentioned that with the passing of time fish weight gain could have influenced feed consumption.

Biological factors affecting feed consumption

Fish size

Different sizes of fish vary in their feed consumption when fed to satiation. Several studies have been performed in which satiation of a particular size of channel catfish has been determined and compared among the sizes. Cacho (1984) found that percent body weight feed consumption was generally higher for the lighter channel catfish than the heavier fish when they were reared in ponds. Feed was provided on an ad libitum basis over a period lasting usually no longer than 30 minutes. Feeds with protein concentrations of both 32% and 26% were provided. The feed was distributed among ponds which contained the following weight classes of fish : small (stocked at 46.5 g), medium (stocked at 152 g), and large (stocked at 550 g). In July, 100.5 g fish consumed 3.36% body weight; 281.5 g fish, 2.65% body weight; and 624.0 g fish, 1.15% body weight. In August, 180.5 g fish consumed 2.44% body weight; 421.5 g fish, 1.62% body weight; and 666.5 g fish, 1.47% body weight. In September, 306.5 g fish consumed 1.58 % body weight; 615.0 g fish, 1.51 % body weight; and 924.0 g fish consumed 1.12 % body weight.

When Silverstein and Freeman (2000) sampled in June, smaller catfish weighing 0.31 ± 0.01 kg (0.69 ± 0.02 lbs) consumed 0.96 ± 0.06 % body weight while the larger fish weighing 0.92 ± 0.01 kg (2.04 ± 0.03 lbs) consumed 0.40 ± 0.02 % body weight. Likewise, they found that catfish weighing 0.39 ± 0.01 kg (0.87 ± 0.03 lbs) consumed 0.83 ± 0.07 % body weight while larger fish weighing 1.24 ± 0.02 kg (2.73 ± 0.04 lbs) consumed 0.42 ± 0.03 % body weight when sampled in September. Both large and small fish were cultured together in the same ponds at a rate of one small fish for every large fish. Fish in the experiment were distributed at a density of 3,237 fish/ha (8,000 fish/acre). Percent body weight consumed was determined by placing lead-oxide beads into the diet and then the fish were provided feed ad libitum. Fish were sampled a minimum of one hour following feeding and were x-rayed to visualize the quantity of beads in the stomach of the fish. The bead count was conveyed on a feed weight basis, which was subsequently calculated in terms of % body weight consumed.

Tackett et al. (1988) utilized demand feeders to evaluate the amount of feed ingested for 0.26 kg (0.57 pound) and 0.04 kg (0.09 lb) channel catfish initially stocked 21 May and harvested 6-7 November. They found that the average feed consumption for 0.26 kg (0.57 pound) channel catfish stocked at 897 kg/ha (200 lb/0.25 acre) was 1.3 ± 1.4 % body weight/day and 1.7 ± 1.5% body weight/ day for fish stocked at 448 kg/ha (100 lb/0.25 acre). They also found that the average feed consumption for 0.04 kg (0.09 lb) fish stocked at 336 kg/ha (75 lb/0.25 acre) was 1.8 ± 1.8% and 1.8 ± 1.6% when fish were stocked at 224 kg/ha (50 lb/0.25 acre). Busch (1986) noted in his study that the larger fish were generally more hesitant to consume the feed provided. The results revealed that feed consumption in channel catfish was 0.7% body weight during the final part of the experiment. This was a substantial decline when compared to the beginning of the study when fish consumed 1.25% body weight. This drop in feed consumption could have been due to an increase in fish size as well as other environmental parameters such as temperature as the seasons changed. Fish were stocked in April and harvested in September/October. The fish had an initial mean weight of 0.68 kg (1.5 pounds) and harvest mean weight of 1.4 kg (3.1 lb). The stocking rate used in the study was 3,707 fish/ha (1,500 fish/acre) and feed was provided on an ad libitium basis for 15-20 minutes.

Page and Andrews (1973) measured feed consumption expressed as % body weight per day for channel catfish that were cultured from 114 g to about 500 g in tanks. The fish were provided six different feeds and fed two times a day on an ad libitum basis. The water temperature in the study was 27.0 ± 0.5 C, ammonia concentrations never surpassed 0.3 mg/L, and DO levels exceeded 7 mg/L. The study found that for all six diets, % body weight consumed per day declined as the fish gained weight. When fish were 114 g, feed consumption was about 5% body weight. However, when the fish grew to 500 g, feed consumption declined to about 2% body weight.

<u>Stocking density</u>

Stocking density may also influence feed consumption. Tackett et al. (1988) found that fish at the elevated densities consumed more feed than fish at the reduced densities when average feed intake per day was compared. Corazza and Nickum (1983) observed that a portion of the fingerling walleye (*Stizostedion vitreum*) in their experiment did not consume any food despite the fact that the amount of food provided always surpassed 10% fish body weight. They concluded that this was a result of lower fish densities and not feeding practices.

Salas-Leiton et al. (2008) conducted an experiment that evaluated the effect of stocking density on feed consumption in fingerling Senegalese sole (*Solea senegalensis*) reared in flow-through tanks. Fish were assigned to tanks at stocking rates of 2, 7, 15, and 30 kg/m^2. The study found that the fish at higher densities consumed more feed (as a % body weight) than fish at lower densities when raised for 60 days. At 2 kg/m^2 , the feed consumption was 0.134 ± 0.01 % body weight while at 30 kg m^2 fish consumed 0.201 ± 0.01% body weight. It was also suggested that the increase in feed consumption might have been due to greater competition, since a reduction in the amount of time needed for fish to start feeding was observed for fish at the highest initial stocking rate. It was also noted that the fish were swimming more vigorously when initially stocked at 30 kg m^2, which may have also been a result of the increased competition among fish. Likewise, Jørgensen et al. (1993) evaluated feed consumption in fingerling Arctic charr (*Salvelinus alpinus*) assigned to tanks at stocking rates of 15, 60, and 120 kg/m^3. X-ray technology (glass beads were put in the feed) was used to assess feed consumption and water temperature in the study was 6.2 ± 0.5 C. They found that feed ingested by fish at the at the elevated stocking rates was greater than feed ingested by fish at the most reduced stocking rate.

Size distribution in ponds

Another variable that may affect feed consumption is the overall size distribution of fish in each pond. If small fish are mixed with larger fish (such as in a multiple-batch system), competition may occur leading to the exclusion of smaller fish from obtaining feed. This may result in the larger fish feeding to satiation while the smaller fish do not. However, there is conflicting evidence of this in the literature.

Unprasert et al. (1999) found that when large and small fish were reared together they did not necessarily compete for feed as a function of fish size. The study assessed feed consumption, at a water temperature of 24 ± 1 C, in channel catfish by using pigmented feed for fish stocked at 24,716 fish/ha in raceways. Fish were assigned to raceways at a proportion of one 54.0 g (average weight) fish for every 402.4 g (average weight) fish. They were provided a restricted ration of feed (1% body weight of red feed followed by 1% body weight of green feed) and were later dissected. The study also assessed feed consumption in channel catfish under pond conditions (at 24,716 fish/ha). Fish were assigned to a pond, with temperatures varying from 26 to 29 C, at a proportion of one 70.4 g (average weight) fish for every 404.7 g (average weight) fish. Fish were fed as in the raceway study and then 10% of each size class was harvested and dissected. The results showed that statistically the % of red feed ingested was lower ($P = 0.048$) in the heavier fish. In the pond study, fish size did not appear to significantly influence the consumption of red feed.

Collier and Schwedler (1990) examined the effect of a fish excluder on weight gain in channel catfish fingerlings stocked into mixed-size ponds. The purpose of this device was to establish a protective location where fingerlings (12.7 g initial weight) could eat without the competition of the larger fish (286 g initial weight). Small fish in the excluder treatment gained statistically more weight than the fish in the treatment lacking the excluders (0.28 ± 0.03 kg/fish vs. 0.17 ± 0.02 kg/fish, respectively). Randolph and Clemens (1976) noted that channel catfish reared in ponds created feeding hierarchies with respect to fish length (small fish = 25 cm, large fish = 46 cm). They also found that the amount of time fish had to wait in order to feed was a function of both fish length and density. For the month of June, the small fish had to wait 4 ± 3.01 hours in a pond that contained 10,000 fish while they only waited 1.1 ± 2.4 hours in a pond containing 3,200 fish.

Freeman (1998) found that channel catfish fingerlings (19 g at stocking) reared in mixed-size ponds were smaller in size (69% smaller in terms of weight) in comparison to the ponds with fish of equal sizes when cultured from June to October. The experiment evaluated the impact of feeds with two different diameters (3.2 mm vs. 6.4 mm) on fish weight gain. The fish in the study were distributed in 0.1 ha ponds at a density of 14,820 fish/ha. Fifty percent of the ponds used fingerling single-batch culture while the other half used ponds comprised of 85% fingerlings and 15% larger fish (stocked at 307g). Feed was provided on an ad libitum basis over a 10-minute period only one time per day.

<u>Genetic strain</u>

Species of catfish and genetic strain may differ in feed consumption. Li et al. (2004) assessed feed consumption in 24.9 g (at stocking) channel catfish (NWAC103 strain) and 31.8 g (at stocking) hybrid catfish that were distributed into ponds at 14,820 fish/ha. Feed was provided to the fish on an ad libitum basis one time per day for 20 minutes. They found that the channel x blue hybrid consumed significantly more feed than the NWAC103 channel catfish (1,012 vs. 838 g/fish, respectively). Jackson et al. (2003) determined feed intake between two lines of channel catfish, the Norris strain (stocked at 3.0 ± 0.08 g) and the NWAC103 strain (stocked at 4.7 ± 0.13 g). Fish in the study were reared in aquaria (flow-through system) at a temperature of 30 ± 1 C and were fed two different feeds, with protein concentrations of 32% and 28%, to satiation and on a restricted basis. Feed intake in the Norris strain was less than the NWAC103 line when the fish were provided the restricted ration. Likewise, feed intake in the Norris strain was less than the NWAC103 when fish were fed to satiation.

Li et al. (1998) compared feed consumption in three genetic lines of channel catfish over an eight week period: USDA102, USDA103, and Mississippi normal. Average fish weight at stocking was 15.1 g and fish were reared in aquaria (flow-through system) at a temperature of 30 ± 1 C. Fish were fed ad libitum two times a day with feed that contained three different levels of protein. The results revealed that the USDA103 channel catfish ate the most feed while Mississippi normal ate the least.

Peterson et al. (2008) determined the effect of genetic strain on feed intake in USDA103, USDA303, USDA102, and USDA102 x USDA103 channel catfish.
The fish at the beginning of the study weighted 27.7 ± 0.7 g and were reared aquaria at a temperature of 26.7 ± 0.3 C. They observed that feed intake in the USDA303 and USDA103 strains was significantly greater than mean feed intake in the other strains. Mean feed intake between the USDA303 strain (90.9 g/fish) and USDA103 strain (89.8 g/fish) was not significantly different. They also noted that the USDA102 strain consumed on average the least amount of feed out of all of the strains (42.4 g/fish).

<u>Frequency of feeding</u>

It is often believed that fish can compensate for times in which food availability is scarce. This concept is especially important with regards to feed intake since fasting fish may result in increased feed consumption when feed is provided again. Numerous studies have been conducted to evaluate feeding frequency on feed consumption in fish. Chatakondi and Yant (2001) conducted an experiment to determine the effect of feed deprivation on feed consumption in 2.5 g channel catfish distributed into aquaria. Fish were assigned to different recurring fasting periods in which feed was withheld for 0, 1, 2, or 3 days. Fish were then fed ad libitum until hyperphagia ceased. The results of the experiment revealed that percentage body weight consumed appeared to be higher for the treatments in which fish were fasted for a longer period of time. Average percent body weight of feed consumed was 5.98% for three days of fasting, 5.36% for two days of fasting, 5.03% for one day of fasting, and 3.91% body weight for 0 days of fasting.

Kim and Lovell (1995) evaluated the influence of restricted feeding schedules on feed consumption (g feed/100 g fish weight/d)in 41 g (weight at stocking) channel catfish reared in ponds for 18 weeks. The feeding schedules used in the experiment consisted of either feeding the fish ad libitum over the entire period or using restricted feeding for 3, 6, and 9 weeks after which fish were then fed on an ad libitum basis. They found that that throughout weeks 0-3, the fish that were fed to satiation every day consumed significantly more feed than any other treatment. In weeks 3-6, feed consumption for the fish that were fed every day and feed consumption in the 3 week restriction treatment were not statistically different but both were significantly greater than the 6 and 9 week restriction periods. Throughout weeks 6-9, feed consumption for the 6-week restriction period was significantly greater than all the other treatments. Likewise, in weeks 9-18, feed consumption in the 9-week restriction treatment was statistically greater than all other treatments.

Evans (1995) assessed the impact of an alternate-day feeding schedule on feed consumption in 569 to 909 g (initial weights) channel catfish in ponds. Fish in the study, which took place from June-September, were either fed to ad libitum each day or provided feed on an ad libitum basis on an alternate day feeding regime. The results of the study revealed that the percent body weight consumed per day for catfish fed on the alternate-day feeding schedule was statistically higher than that of fish provided feed each day on an ad libitum basis. Mean feed consumption for catfish that were fed each day to satiation was 1.53% body weight/day while fish on the alternate day schedule consumed 2.48% body weight/day.

Rate of passage in the digestive system

The rate of passage of feed through the digestive system may also influence feed consumption in fish. Grove et al. (1978) observed that the return of fish hunger and the emptiness of the stomach were closely connected in rainbow trout (*Salmo gairdneri)*. They also demonstrated that gastric emptying was influenced by fish size as well as temperature and the energy content of the feed. Brett and Higgs (1970) examined the influence of temperature (3, 5, 10, 15, 20, and 23 C) on the rate of stomach emptying in 30-40 g sockeye salmon *Oncorhynchus nerka* stocked into tanks and fed ad libitum. Results indicated that temperature had a substantial effect on the rate of gastric evacuation. For instance, it took 147.0 h for 99% evacuation of the feed at 3 C while it only took 17.8 h at 23 C.

Studies in several fish species have been conducted with respect to rate of passage of food through the digestive system (Booth et al. 2008; Corazza and Nickum 1983; Rozin and Mayer 1964) including channel catfish (Shrable et al. 1969). Shrable et al. (1969) conducted a study to determine the quantity of feed (expressed as a % on a dry matter basis) left in the digestive tract of 380 g channel catfish as a function of time and temperature. They found that that when fish were force-fed, the percentage of dry feed left in the stomach and intestine two hours after feeding was 84.21% at 21.1 C, 89.19% at 26.6 C, and 92.07% at 29.4 C. The percentage of dry feed left in the stomach and intestine 10 hours after feeding was 82.41% at 15.5 C, 57.01% at 21.1 C, 40.23% at 26.6

C, and 44.01% at 29.4 C. The percentage of dry feed left in the stomach and intestine 24 hours after feeding was 25.35% at 15.5 C, 13.57% at 21.1 C, 6.02% at 26.6 C, and 4.21% at 29.4 C.

Feed quality

Catfish feed consumption has been shown to be directly associated to the protein concentration and energy content of a feed. Page and Andrews (1973) evaluated the impact of different concentrations of energy and protein (35% and 25%) on feed consumption in channel catfish They observed that that there was a significant correlation between the energy content and feed consumption. The trend was that as the energy content increased, feed consumption decreased. Lovell (1979) also determined that feed intake in fingerling channel catfish reared in aquaria declined as the caloric content in the feed was raised. Three different amounts of digestible energy content were analyzed in the study: 230, 290, and 350 kcal/100 g. He also found that when feeds with protein contents of 23, 29, and 35% were compared in the first part of the experiment there was no significant difference in feed consumption among the protein levels when the energy content stayed the same. Feed was provided two times a day on an ad libitum basis for 30 minutes and the temperature was maintained at 29 ± 1 C. Any unconsumed feed was quantified and siphoned out of the aquaria throughout the four week duration of the experiment. The experiment was expanded upon for four extra weeks by including a broader spectrum of protein concentrations (15-65%). The results revealed that feed consumption was not influenced by protein content from 15- 45% protein, but when protein concentrations were higher than 45%, feed consumption appeared to weaken. Feed consumption was significantly at its lowest in the 65% protein treatment.

The bulkiness of the diet also appears to influence feed consumption. Lovell (1979) determined that channel catfish in ponds provided a 36% protein and 280 kcal/100 g of digestible energy feed ate significantly more feed (in terms of kg consumed per fish) than fish that were provided a 30% protein and 250 kcal/100 g of digestible energy feed. The fish initially weighed 83 g (mean weight) and were distributed into 0.04-ha ponds at a rate of 5,000 fish/ha where they were grown to about 400-500g. Feed was administered on an ad libitum basis for 45 minutes. It was identified that the feed with the reduced protein/caloric content had enlarged during the extrusion process, which yielded a reduction in density with respect to the feed with the greater energy/protein content (0.83 g/cm^3 vs. 0.91 g/cm^3 respectively). It was suggested that the lower feed intake occurred since the fish were not able to retain as much of this expanded feed in their stomachs.

III. MATERIALS AND METHODS

Treatments

The study was designed to determine feed consumption of various size classes of hybrid catfish over a range of water temperatures and the effectiveness of satiation feeding to estimate biomass. The nominal treatments were fish sizes: fingerlings, stockers, market, and large market; and water temperatures: 15, 20, 25 and 30 C. Each combination of fish size and temperature was designed to have a total of four replicates, two sampled in the spring and two in the late summer/fall. However, for the large food-sized fish only one replicate was obtained for first 20 C and 30 C sampling periods. Likewise, only one replicate of the stockers was obtained during the first 20 C sampling period due to a lack of available fish.

Procedures

Hybrid catfish were stocked into 0.04-ha ponds at a density of 4,000 fish/ha, by size categories of fingerlings (67.0 ± 18.2 g), stockers (162.5 ± 36.1 g), food-size (507.5 ± 121.4 g), and large food-size (1,327.5 ± 236.7 g). Large food-size fish were stocked at a lower density of approximately 1,750 fish/ha. The fish were fed at water temperatures of 15 C (15.6 ± 0.8), 20 C (21.8 ± 1.7), 25 C (24.9 ± 1.0), and 30 C (29.1 ± 1.0). Ponds were treated with approximately 2 mg/L Aquashade ® or as needed in order to control aquatic weeds. Fish were stocked at least seven days prior to the start of a satiation feeding trial and fed until an active feeding response was observed. Once the proper experimental pond temperature was reached, fish were fed to satiation a 32% protein floating commercial diet, a minimum of three times the week prior to sampling. Fish were fasted one day prior to sampling the pond in order to allow the stomach to clear. For the 15 C treatment, fish were not fed two days prior to sampling due to the cooler temperature. Fish were fed to satiation for 10 minutes and were subsequently provided an additional 35 min to clean up any uneaten feed. Forty-five minutes after the start of satiation feeding all remaining floating pellets were counted. The pellets were not removed from the pond. The number of pellets were converted to a dry pellet weight based on number of pellets/g dry pellet weight feed and subtracted from the total weight of feed provided in order to obtain the apparent weight of feed consumed by the fish.

The total weight of feed consumed was also calculated, correcting for the percent that actually floated. This was done by multiplying the fraction that floated by the quantity of feed consumed. This correction factor made the assumption that fish only consumed the percentage that floated and ignored the feed that sank to the bottom of the pond. During the study period a total of five batches of feed were used. For each batch of feed, 250 pellets were taken from the storage bin and 50 pellets were added to five different 18.9-L buckets filled with water. The number of pellets floating after 45 min was counted and expressed as percentage of the total.

The ponds were seined 45 minutes after the start of feeding on the day of sampling. A sample of 25 fish was selected and placed immediately on ice. For the large market fish that were missing a replicate pond, a sample of 50 fish was obtained. After the sample was taken, the rest of the fish in the seine haul were harvested and transported to holding tanks where the fish were held approximately 24 hours. Ponds were drained and the next day the remaining fish were harvested. The total fish biomass of the pond was determined approximately 24 hours after sampling. The percent body weight consumption per fish was determined by weighing each fish, dissecting the stomach and counting the number of pellets. The number of pellets per unit weight of dry pellet weight feed was determined in advance. Feed consumption was expressed as a percentage of dry pellet weight of feed consumed per whole wet weight of fish.

Water temperature and dissolved oxygen were measured with a YSI Model 85 oxygen meter (YSI Incorporated, Yellow Springs, Ohio, USA) right before the start of each satiation feeding estimate. Both pond temperature and dissolved oxygen were measured at about 50 cm below the pond surface as the meter probe was swayed from left to right. Other water quality parameters, such as pH, total ammonia, alkalinity and hardness were also measured within 24 hours of sampling using LaMotte kit model AQ-2 (LaMotte Company, Chestertown, Maryland, USA). Parameters such as barometric pressure, maximum daily wind speed, solar radiation, and precipitation, were also obtained for each satiation estimate. Maximum daily wind speed, solar radiation, and precipitation data were obtained from the Agricultural Weather Information Service, Inc. (http://www.awis.com/mesonet) while barometric pressure data was obtained from Weather Underground, Inc (http://www.wunderground.com).

Data analysis

Actual vs. estimated biomass

Biomass was determined as actual total biomass harvested per pond, as well as biomass estimated based on satiation feeding, where biomass = quantity of feed consumed / % body weight consumed. This was done for all fish size and temperature combinations. Estimated biomass was determined based on a number of potential correction factors as described below.

Satiation feed estimates

To determine estimated biomass based on satiation, the knowing the quantity of feed consumed is a key factor. Satiation is based on knowing the quantity of feed given and counting the number of feed pellets still floating 45 min after the first feed was first given. In this study, the percentage of feed offered that was still floating after 45 minutes for each satiation estimate was determined by dividing the quantity of feed floating after 45 minutes by the total amount of feed put into the pond (expressed as a percent). The percentage of the feed left over was compared to the total quantity of feed provided for all size classes at all temperatures by linear regression. Satiation based on the use of floating feed typically assumes that 100% of the feed given floats, however, this is generally not true. In this study, the percent of floating feed in each batch of feed used was determined as described earlier. This information was used to estimate satiation based on the four perspectives of "uncorrected apparent satiation", "corrected apparent satiation", "average weekly satiation", and "corrected average weekly satiation". The "uncorrected apparent satiation" was determined by the total quantity of feed given – quantity of feed still floating after 45 min. The "corrected apparent satiation" was calculated as: (total quantity of feed given * % of feed that actually floated) – quantity of feed still floating after 45 min. The apparent "average weekly satiation" consumed was generated by obtaining a mean of each apparent satiation estimate obtained prior to the day of sampling as well as the estimate from the day of sampling. The "corrected average weekly" satiation was calculated similarly to the "corrected apparent satiation" except it took the fraction of feed floating for the "weekly average" instead of the "apparent satiation".

Percent body weight consumption as determined by dissection or total biomass

To assess estimated biomass based on satiation, the determination of the percent body weight consumed is another key factor. Percent body weight consumed was determined as "actual percent body weight consumed" or "apparent percent body weight consumed". The "actual" percent body weight consumption was determined by the dissections of 25 fish per pond. The "apparent" percent body weight consumed was calculated based on the quantity of feed applied to the pond and assumed to be consumed divided by the biomass of fish actually harvested. The method to determine "apparent percent body weight consumed" was selected based on the previously described four perspectives of "uncorrected apparent satiation", "corrected apparent satiation", "average weekly satiation", and "corrected average weekly satiation" which were all expressed on a percent body weight basis based on the total biomass of the pond. The results of the comparison between apparent satiation, corrected apparent satiation, average weekly satiation, and the actual samples of 25 fish were then used to verify the accuracy of the biomass estimations. This was first done by using an ANOVA to compare % body weight consumed among each technique for fish of all sizes and temperatures, fish of all sizes at a common temperature, and fish of a common size class at all temperatures. Linear regression was used to compare which of the "apparent" techniques had the strongest association when compared to the "actual satiation". "Corrected apparent satiation" was selected for evaluations of effects of fish size, and environmental parameters.

Actual percent body weight consumption and factors affecting consumption

Multiple linear regression was used to compare % body weight consumed to average weight, pH, total ammonia, temperature, DO, alkalinity, hardness, solar radiation, maximum wind speed, and barometric pressure. This was done in order to determine the parameters that significantly influenced feed consumption and to see which ones yielded a greater impact on % body weight consumed.

Fish size and water temperature

For biomass estimations to be accurate, the percent consumption needs to be predicable for a given size fish at a given temperature. Feed consumption expressed as a percent body weight was obtained for each individual fish during the dissections. However, due to the lack of replicates for several of the ponds, it was necessary to pool individual fish from all available replicates in a given treatment together for the subsequent analyses. This feed consumption will be referred to as “pooled” consumption in the following paragraphs within the Materials and Methods section. It is important to note that this is different from the “actual” feed consumption, which represents the mean feed consumption from the 25 fish sample in a single pond.

Fingerlings and stockers were grouped together as “small fish” and the market and large market fish were grouped together as “large fish”. The mean pooled feed consumption as % body weight consumed for both groups was compared with a t-test. Mean pooled feed consumption at a common temperature was then compared among fingerlings, stockers, market size fish, and large market fish by using ANOVA with the Tukey-Kramer multiple comparisons post-test. Likewise, the mean pooled feed consumption for different temperature treatments were compared for fish of a common size class by using ANOVA with the Tukey-Kramer multiple comparisons post-test. The water temperature used in the experiment was the one taken at the pond before feeding the fish to satiation. However, Onset StowAway® TidbiT® temperature loggers were also used to obtain a 24-h average temperature in several of the ponds. Both temperature readings were compared by ANOVA. The effect of individual temperature variation on feed consumption within a given temperature treatment was analyzed by using linear regression for fish of all sizes.

The Q_{10} temperature coefficient can be described as "the increase in the rate of a physiological process resulting from a 10 C increase in temperature" (Jobling 1994). It is calculated as : $Q_{10} = (V_2/V_1)^{10/[T(2)-T(1)]}$ "where V_1 and V_2 are the rates of the physiological process measured at temperatures *T*(1) and *T*(2), respectively" (Jobling 1994). In this study, the Q_{10} temperature coefficient was determined for feed consumption by plugging the pooled mean feed consumption for each size class at 20 and 30 C into the formula mentioned above. The Q_{10} values were then visually compared (not statistically) to see if a specific size class was more sensitive to a change in temperature than the others. The magnitude of change by each size class as a function of temperature, where consumption at 25 C is used as the baseline consumption, was also calculated using the mean pooled feed consumption (% body weight consumed).

Seasonal effect, spring vs. summer/fall

The seasonal effect on feed consumption was assessed by using a t-test to compare the average pooled feed consumption of individual fish from the first sampling period to that of the second sampling period (i.e. spring vs. late summer/fall). The effect of season was analyzed for fish of all sizes at a given temperature as well as individual fish sizes at specific temperatures by using a t-test.

Variation in feed consumption among individual fish and ponds

The impact of individual fish size variation on pooled feed consumption within a given size class (fingerling, stocker, market, large market) was analyzed by using linear regression at each temperature. Variation in feed consumption (% body weight) for individual fish was assessed by comparing coefficients of variation. Coefficients of variation were generated and compared for fish of a specific size class at all temperatures to assess the variability in pooled feed consumption among the different size classes. Likewise, coefficients of variation were calculated and compared for fish of all sizes within a specific temperature treatment in order to analyze the variability in pooled feed consumption among the different temperature treatments. The percentage of fish that were not consuming any feed, when individual fish were pooled together, for fish of a specific size class at a specific temperature was determined. If fish consumed less than 0.25% of their body weight, then it was considered that they were not feeding.

The modal and mean pooled feed consumptions as a function of fish size and water temperature were generated for only fish that were feeding and also for all fish (including the non-feeders). The mode was represented by 0.25 intervals (0-0.25% body weight, for example). The means and modes were then compared in order to see whether or not the non-feeding fish were influencing average feed consumption. The mean was considered equal to the mode if it fell within the 0.25 modal interval. If the mean was less than the lower end of the modal interval, then mean feed consumption was considered to be less than modal feed consumption. If the mean was greater than the upper end of the modal interval, then mean feed consumption was considered to be greater than modal feed consumption.

Feed consumption between replicate ponds within a given sampling period were compared by a t-test for each size and temperature class using the feed consumption from each individual fish from the dissections for each pond. The variability in feed consumption from one day to another was also determined for fish of a common size and temperature for all satiation feedings, which included the satiation estimates on the day of sampling as well as the three days (or more) prior to sampling. This variation in feed consumption from one day to another was calculated similarly as in Tackett et al. (1988) and Evans (1995) as : 100 x (quantity consumed - quantity consumed the day prior) / quantity of feed consumed the day prior.

Effect of water quality parameters on feed consumption

DO, pH, ammonia (TAN), alkalinity, total hardness, barometric pressure, wind speed, solar radiation, day length, and precipitation were all compared to feed consumption for fish of all size classes at all temperatures by linear regression. If the P-value was less than 0.2, then fish of all size classes at all temperatures were analyzed by linear regression to better define any trend. Similarly if $P < 0.2$, then fish of a common size class at all temperatures were also analyzed by linear regression. Precipitation was also analyzed with a t-test to compare feed consumption between days in which it rained vs. days when it did not.

<u>Biomass estimations</u>

Once the appropriate estimates of satiation and % body weight feed consumption were obtained by applying the appropriate correction factors, then the biomass of the pond could be estimated. Biomasses were also expressed as standing crops on a kg/ha basis. Standing crop estimates were obtained using both uncorrected and corrected data to determine if a specific correction factor improved the standing crop estimation. As previously mentioned, estimated biomass was calculated by dividing the mean quantity of feed consumed per pond by the mean percent body weight consumed. This value was then converted to kg/ha and compared to the "actual standing crop" of the pond. The actual standing crop of the pond was determined by obtaining the weight per unit area of all fish from the day of harvest within approximately 24 h from the day of sampling.

Estimated and actual standing crops were first compared when no correction factors were made. Subsequently, actual and estimated standing crops were compared after the correction factors were applied. The way in which accuracy was assessed was by determining the percent difference between the actual and estimated standing crops using the actual standing crop as the standard for comparison. Ponds with estimated standing crops that differed by approximately ≤ 5% of the actual standing crop were considered to be very effective in estimating standing crop. Likewise, ponds with estimated standing crops that differed ≤ 10% of the actual standing crop were considered to be effective in estimating standing crop. The ponds that were considered to be effective and very effective in determining standing crop were then divided by the total number of ponds to obtain a percentage of the efficacy of estimating standing crop. The efficacy of predicting standing crop between the data that used no correction factors vs. the data that used the correction factors was assessed by observing which estimation had a higher frequency of ponds that were with 5 or 10% of the actual standing crop.

The technique with the highest accuracy was then compared to the actual standing crop at harvest by linear regression for all size classes at all temperatures. Actual standing crop was then compared to the estimated standing crop for fish at a specific temperature independent of size as well as fish of a specific size independent of temperature with linear regression. Another topic of interest was to see if the standing crop was consistently being underestimated or overestimated for fish of all sizes at all temperatures, for fish at a specific temperature independent of size, and for fish of a given size class independent of temperature. This was assessed by determining the frequency of occurrences in which the estimated standing crop was either over or underestimated and then put on a percentage basis. The magnitude of over/underestimating standing crop was obtained by taking the average percent change between actual and estimated standing crop for all standing crop estimates that were overestimated as well as all standing crop estimates that were underestimated.

Standing crop estimates were also calculated using the modal feed consumption in each pond. Since the modes obtained were intervals of percent body weight consumed (i.e. not a specific single number), the average of the upper and lower level of each interval was used to calculate standing crop. Modal standing crop was calculated both assuming that all feed was consumed and that only the fraction of feed that floated was consumed.

IV. RESULTS

Nominal treatments

The nominal temperature treatments of 15, 20, 25, and 30 C had actual mean temperatures of 15.6 ± 0.8 C, 21.8 ± 1.7 C, 24.9 ± 1.0 C and 29.1 ± 1.0 C, respectively. The mean weights for the size categories of fingerling, stockers, market and large market were 67.0 ± 18.2 g, 162.5 ± 36.1 g, 507.5 ± 121.4 g, and 1,327.5 ± 236.7 g, respectively. Mean water quality values for fish of all sizes at all temperatures treatments are given in Table 1.

Satiation feeding

To estimate biomass based on satiation, an accurate estimation of satiation is necessary. Use of floating feed is thought to facilitate estimating satiation assuming that the feed offered floats. In this study, five batches of feed were used and the percent that floated was 72.5%, 78.4%, 72.8%, 87.2%, and 66.0%. Satiation was based on knowing the number of pellets given and counting the number of feed pellets still floating 45 min after the first feed was first given. The percentage of feed offered that was still floating after 45 min ranged from 0 to 87.2% of the quantity given. There was a linear relationship between the percentage of feed left over and the quantity of feed provided for all size classes at all temperatures (R^2 = 0.255, P = 0.0001). The observed trend was that as the quantity of feed provided increased then percentage of feed left over decreased. The maximum daily feed input was 87.5 kg/ha for one of the ponds with the market fish during the 30 C temperature trial.

Actual vs. apparent feed consumption

The quantity of feed consumed as a percent fish body mass as determined by dissection or as apparent feed consumed for the biomass harvested was variable reflecting differences in temperature and fish size (Tables 2-3). The overall mean feed consumption (% body weight) for all sizes at all temperatures was 1.38 ± 1.32% for the actual feed consumption as determined by dissection. Apparent consumption the day of sampling as a percent biomass harvested was 1.68 ± 1.60% based on feed offered and apparently consumed, and 1.29 ± 1.20% when corrected for the percent of feed that sank. Apparent consumption (% biomass) based on the weekly mean quantity of feed consumed was 1.55 ± 1.41%, and 1.19 ± 1.07% when adjusted for just floating feed (Table 2). When all methods for assessing satiation were compared by ANOVA for all fish sizes and temperatures, there were no significant treatment differences based upon each technique ($P=0.325$) due to the variability associated with fish size and temperature. The actual % body weight consumed as determined by dissection was best correlated to daily apparent consumption corrected for the quantity of feed that floated ($R^2 = 0.934$, $P <0.0001$) (corrected apparent) or uncorrected daily apparent consumption ($R^2 = 0.923$, $P < 0.0001$) (apparent consumption). Estimating consumption based on a weekly average showed less of a relationship to actual consumption with weekly average apparent consumption at $R^2 = 0.790$, $P < 0.0001$, or when corrected for sinking feed ($R^2 = 0.781$, $P < 0.0001$).

Actual percent body weight and factors affecting feed consumption

A multiple linear regression model that compared % body weight consumed to average weight, pH, ammonia, temperature, DO, alkalinity, hardness, solar radiation, maximum wind speed, and barometric pressure was analyzed. The percent of the variation explained by the model was 63.1% (R^2) and the overall model was significant ($P < 0.0001$). The only variables that made a significant contribution to the model were average weight ($P < 0.0001$) and temperature ($P = 0.001$). Hardness was not significant at $P < 0.05$, but it was significant at $P < 0.1$ ($P = 0.058$). Out of all parameters analyzed in the model, average weight contributed most to the model (standardized beta coefficient = -0.529) followed by temperature (standardized beta coefficient = 0.528) and then hardness (standardized beta coefficient = 0.432).

<u>Fish size and temperature</u>

Mean feed consumption for each size class of fish at the temperatures tested are given in Table 4. At all temperatures, smaller fish (fingerlings and stockers combined) consumed more than larger fish (market and large market combined) ($P < 0.0001$). At 20 C and 30 C, fingerlings and stockers consumed similar amounts as percent body weight ($P > 0.05$), but in the 25 C treatment, stockers consumed significantly more than fingerlings ($P < 0.001$). Large market fish ate less than 1% body weight at all temperatures when mean feed consumption was compared.

Water temperature had a significant effect on feed consumption by all size classes ($P < 0.0001$) (Table 4). The mean temperatures for the nominal temperature treatments were 15.6 ± 0.8 for 15 C, 21.78 ± 1.72 for 20 C, 24.92 ± 0.99 for 25 C and 29.09 ± 1.01 for the 30 C treatment when recorded just prior to feeding the fish to satiation on the day of sampling. Temperatures were also calculated as 24-hour averages and were compared to those at the day of sampling. There was no significant difference between both temperatures recorded just prior to feeding or the mean 24-h temperature for the period prior to feeding for the 15, 20, 25, and 30 C temperature treatments ($P > 0.05$).

The effect of individual temperature variation on feed consumption within a given temperature treatment was tested by using linear regression for all fish sizes. There was no significant linear relationship between feed consumption and individual temperature at 15, 20, and 30 C. However, there was a slight linear relationship between feed consumption and temperature at 25 C but the association was weak ($R^2 = 0.256$, P = 0.045).

Highest rates of feed consumption (% body weight) did not necessarily occur at the highest temperatures for all size classes (Table 4). The greatest feed consumption for the fingerling and market size classes was at 30 C. However, for the stockers and large market size classes, there was no significant difference in feed consumption between 25 C and 30 C ($P < 0.0001$). The lowest feed consumption for all size classes occurred at 15 C. At 15 C, the feeding activity was limited and the mean percent body weight consumption for stockers, market, and large market fish were similar ($P > 0.05$) and averaged less than 0.07 % body weight. Feed consumption by large market fish did not significantly increase at 20 C ($P > 0.05$) averaging 0.003 ± 0.006 and 0.111 ± 0.243%, respectively, at 15 C and 20 C. Fingerlings were the most active feeders at 15 C consuming an average of 0.07 ± 0.13% body weight.

<u>Seasonal effect, spring vs. summer/fall</u>

For all sizes of fish, there was no significant difference in feed consumption between seasons at 20 C (P = 0.651), but at 25 C and 30 C there was a significant difference between seasons ($P < 0.0001$). At 25 C, feed consumption was greater during the spring ($P < 0.0001$). At 30 C, feed consumption was greater during the late summer ($P < 0.0001$). For the fingerlings at a common temperature, there was a significant difference between the two different seasonal sampling periods at all temperatures. In both the 20 C and 25 C treatments, feed consumption was greater during the spring. For the 30 C treatment, feed consumption for the fingerlings appeared to be greater in late summer ($P < 0.0001$). Feed consumption by stockers varied seasonally at 20 C and 30 C, but not at 25 C. At 20 C and 30 C, stockers consumed more during the late summer/fall than in the spring ($P < 0.0001$ and $P = 0.0038$ respectively). Consumption by market fish did not differ seasonally at 20 C ($P = 0.1563$) or 30 C ($P = 0.2135$). At 25 C, market fish consumed more feed during the spring ($P < 0.0001$). There was a seasonal effect at all temperatures for the large market fish, except for the 30 C temperature treatment. At both the 20 C and 25 C, feed consumption was greater during the spring ($P < 0.0001$).

Effect of water quality parameters on feed consumption

Mean water quality parameters on the day of sampling and are given in Table 1.

Dissolved Oxygen

There was no significant linear relationship when comparing feed consumption (% body weight) to DO as mg/L ($R^2 = 0.11$, $P = 0.45$) or percent saturation ($R^2 = 0.023$, $P = 0.28$) on the day of sampling over the ranges of 5.35 to 11.37 mg/L and 66.0 to 137.1 % saturation.

pH

The pH at the time of sampling ranged from 6.7 to 9.0 with a mean of 7.2 ± 0.47. There was no linear relationship between feed consumption and pH ($R^2 = 0.009$, $P = 0.501$).

Ammonia (TAN)

Ammonia levels, which ranged from 0.04 to 0.94 mg/L, did not appear to significantly influence feed consumption (% body weight) for the fingerlings ($R^2 = 0.037$, $P = 0.508$) and large market fish ($R^2 = 0.068$, $P = 0.409$). There was, however, a positive linear relationship between % body weight consumed and ammonia for the stockers ($R^2 = 0.436$, $P = 0.019$) and market size fish ($R^2 = 0.347$, $P = 0.026$). As feed consumption increased, ammonia concentrations also increased.

Alkalinity

When feed consumption (% body weight) for fish of all sizes and temperatures was compared to the alkalinity of the ponds, which ranged from 32 to 68 mg/L, there appeared to be no linear relationship between the two variables ($R^2 = 0.040$, $P = 0.154$). When % body weight consumed was compared to the alkalinity of the pond for fish of a given size class independent of temperature, there was no significant linear relationship between the two variables ($P > 0.05$). Likewise, there was no significant linear association between feed consumption (% body weight consumed) and alkalinity when fish of all sizes at a common temperature were compared ($P > 0.05$).

Total Hardness

When mean percent body weight consumed for fish of all sizes and temperatures was compared to the total hardness of the ponds, which ranged from 28.0 to 56 mg/L, there was a very weak relationship between the two variables ($R^2 = 0.075$, $P = 0.048$). When fish of all sizes at a common temperature were analyzed, there was a very slightly significant linear relationship between the two variables at 30 C ($R^2 = 0.289$, $P = 0.047$). At 30 C, as hardness increased over the range of 28-52 mg/L, the percent body weight consumed increased to 3.7 times as much as that of the lowest value.

Effects of meteorological conditions on feed consumption

Barometric pressure, which ranged from 29.69 to 30.34 inches, did not appear to significantly influence feed consumption (% body weight) when fish of all size categories at all temperatures from the day of sampling were combined ($R^2 = 0.008$, P = 0.499). In addition, maximum wind speeds, which ranged from 14.5 to 43.5 km/h (9 to 27 mph), had no effect on feed consumption (% body weight) during the day of sampling for fish of all sizes at all temperatures ($R^2 = 0.007$, P = 0.560).

Solar radiation, which ranged from 609 to 7,510 watt-hours per m^2 did not appear to influence feed consumption (% body weight) for fish of all sizes at all temperatures on the day of sampling ($R^2 = 0.027$, P = 0.237). Precipitation, which ranged from 0 to 2.90 cm (0 to 1.14 inches) on the days of sampling, had no significant effect on feed consumption (% body weight) for fish of all sizes at all temperatures on the day of sampling ($R^2 = 0.004$, P = 0.629). When feed consumption was compared between the days it rained vs. days when it did not, there was no significant difference between the two variables (P = 0.65).

Day length, which ranged from 10.4 to 14.3 hours throughout the entire experiment, appeared to have no significant influence on feed consumption when fish of all sizes at 20 C, 25 C, and 30 C were compared ($R^2 = 0.078$, P = 0.062). When day length was compared to feed consumption during spring and early summer for fish of all sizes and temperatures, there was no significant linear association between the two variables ($R^2 = 0.033$, P = 0.430). However, there was a significant linear association between feed consumption and day length for fish of all sizes at all temperatures (excluding the 15 C) during the late summer and fall sampling periods ($R^2 = 0.173$, P = 0.044). The observed trend during the fall was that as day length decreased, so did feed consumption. In order to see if this association between day length and feed consumption was due to the effect of temperature, a multiple linear regression comparing feed consumption to both day length and temperature was performed for all size classes during the late summer/fall sampling period. The results of the multiple linear regression confirmed that the relationship between feed consumption and day length may actually be due to the coinciding decreasing temperature and not solely due to photo phase ($P > 0.05$).

Variation in feed consumption among individual fish and ponds

The effect of individual fish size variation on feed consumption within a given size class was tested by using linear regression at each temperature. There was no strong linear relationship between feed consumption and individual fish weight for any of the treatments. Feed consumption (% body weight) for individual fish was variable and the magnitude of the variability differed by both size and temperature. The coefficient of variation was generally greater the larger the fish size class. The fingerlings, stocker, market, and large market fish at all temperatures had coefficients of variation of 79.8, 68.2, 117.8, and 175%, respectively. Feed consumption (% body weight) was more variable among individual fish at the lower the water temperature. When all size classes of fish were grouped into the 15 C, 20 C, 25 C, and 30 C temperature treatments, the coefficients of variations in feed consumption was 366.7, 117.5, 98.0, and 76.9%, respectively. At all fish sizes and temperature combinations, there were a portion of the fish in the sample that did not feed (Table 5). The proportion of fish without feed in the stomach varied with temperature with the greatest percent of fish without feed being at 15 C. The proportion of fish without feed in the stomach also varied with fish size with the greatest percent of fish without feed being the large market fish at 100% at 15 C, 84% at 20 C, 67% at 25 C, and 65% at 30 C. The greatest percent of fish with feed in the stomach were the stockers at 30 C where 100% had feed in the stomach.

As described in the Materials and Methods section, feed consumption between replicate ponds within a given sampling period were compared for each size and temperature class. However, one replicate was missing for both the stockers and large market fish at 20 C during the spring as well as one missing replicate for the large market fish at 30 C during the early summer. Therefore, it was not possible to compare replicates between those treatments. There was a significant difference between replicates for all temperature and size classes ($P < 0.05$) except for the stockers at every temperature, the fingerlings at 20 C during the spring, the market fish at 15 C, the market fish at 20 C during the spring, the large market fish at 15 C, the large market fish at 20 C during the spring, and the large market fish at 30 C during late summer. When ponds were fed three or more days to satiation, a substantial amount variability from one day to another in quantity of feed consumed was documented (Table 6). Variability in feed consumption from one day to another for any given pond (for fish of all sizes at all temperatures) would vary on average 38.2 ± 111.3 %, ranging anywhere from 0 to 1,615.7%.

The modal and mean feed consumptions as a function of fish size and water temperature are given in Table 7. The means and modes were compared for all fish (both feeding and non-feeding combined) in order to see whether or not the non-feeding fish were influencing average feed consumption. In general, at 15 C both the means and modes appeared to be similar for each size class of fish. At 20 C, the mean appears to be greater than the mode for all size classes except the large market size fish with equal mean and mode. At 25 C, the mean percent body weight consumed for all size classes was larger than the mode. However, although the mean was slightly greater than the mode for the stockers and large market fish at 25 C, the difference between means and modes for both sizes is not very large. At 30 C, the mode was larger than the mean for the fingerlings, while the mean was greater than the mode for the market fish and only slightly greater for the large market fish. The mode appears to be equal to the mean for the stockers at this temperature (Table 7).

<u>Effect of survival rate on feed consumption</u>

Overall, feed consumption was not correlated to survival, which ranged from about 72.4% to 100% at harvest. ($R^2 = 0.037$, $P = 0.168$). Average survival for all fish sizes and temperatures was 95.5 ± 6.2 %. However, at 15 C there appeared to be a marginally significant linear relationship ($R^2 = 0.53$, $P = 0.04$) between survival and feed consumption, with percent body weight consumed increasing as survival decreased. When percent survival was compared to percent body weight consumed for fish of a specific size class at all temperatures there was no significant linear relationship between the two variables ($P > 0.05$) for all size classes except for the large market fish ($R^2 = 0.81$, $P < 0.0001$). For the large market fish, where survival was lower the percent body weight consumed actually increased.

Biomass estimations

Fish biomasses, expressed as the standing crop at the time of sampling, ranged from 215.9 to 3,270.4 kg/ha. Estimated standing crops were calculated based on satiation feeding as = feed fed / % body weight consumed/ha. This was based on the actual % body weight consumed, which was determined by the dissections. The quantity of feed fed was considered from two views as discussed earlier: the actual quantity of feed given and the actual quantity feed given minus the quantity that sank. When using the total quantity of feed given, the estimated standing crops were within 10% the actual standing crops only on 11.5% of the occasions (Tables 8-9). Standing crops estimated based on the quantity of feed given discounting the quantity of feed that sank gave estimates that were within 10% of the actual standing crops on 30.8% occasions (Tables 10-11). Due to this improvement in accuracy, standing crop estimates adjusted for the sinking feed were used in subsequent analyses. Standing crop estimates were also calculated using the mode of each pond; however, only 15.6% of the estimated standing crops were within 10% of the actual standing crops when the mode was used to calculate standing crop assuming that only the floating feed was consumed.

There was a significant linear relationship between the estimation of standing crop based on adjusted satiation feeding and the actual standing crop from the day of harvest for fish of all sizes at all temperatures ($R^2 = 0.58$, $P < 0.0001$). However, there was no consistent trend. Standing crops were overestimated 38.5% of the time with the average overestimation being 42.4 ± 59.5% greater than the actual standing crops. Standing crops were underestimated 61.5% of the time with the average underestimation being 21.2 ± 20.1% less than the actual standing crops.

Temperature had a notable effect on the similarity between the actual and estimated biomasses. Estimated biomass was most similar to the actual biomass at 30 C ($R^2 = 0.96$, $P < 0.0001$) but with no consistent pattern (Fig. 1). Fifty-three percent of the biomass estimates underestimated actual biomass while 47% overestimated actual biomass. The magnitude of the difference from actual was on average by 6.30 ± 4.72 %

for the underestimation and 17.26 ± 12.56% for the overestimations. At 25 C, there was also a linear relationship between the actual and estimated biomasses ($R^2 = 0.42$, $P = 0.006$). Fifty-six percent of biomass estimates underestimated actual biomass while 44% overestimated biomass. The underestimates differed on average from actual by 21.10 ± 20.20% and the overestimation by 61.96 ± 88.68%. At 20 C, there was also a linear relationship between the actual and estimated biomasses ($R^2 = 0.63$, $P = 0.0007$). Seventy-nine percent of the biomass estimates underestimated actual biomass while 21% overestimated biomass. Biomass estimates were on average underestimated by 21.26 ± 16.00% or overestimated by 76.53 ± 54.81% relative to the actual. At 15 C, there was a linear relationship between the actual and estimated biomasses ($R^2 = 0.78$, $P = 0.008$). Fifty-seven percent of biomass estimates underestimated actual biomass while 43% overestimated biomass. Biomass estimates were on average underestimated by 51.43 ± 19.23% or overestimated by 21.20 ± 23.85%.

Fish size also had a substantial effect on the similarity between the actual and estimated biomasses. Estimated biomass was most similar to the actual biomass for the stockers at all temperatures ($R^2 = 0.74$, $P = 0.0003$). Eighty-three percent of biomass estimates for the stockers underestimated actual biomass while 17% overestimated biomass. Biomass estimates for the stockers were on average underestimated by 20.33 ± 17.61 or overestimated by 5.50 ± 4.67%. For the fingerlings at all temperatures, there was no linear relationship between actual and estimated biomass ($R^2 = 0.0006$, $P = 0.934$). For the market size fish at all temperatures, there was no linear relationship between actual and estimated biomass ($R^2 = 0.15$, $P = 0.168$). For the large market size fish at all temperatures, there was a linear relationship between actual and estimated biomass ($R^2 =$

0.38, P = 0.031). Forty-two percent of biomass estimates underestimated actual biomass while 58% overestimated biomass. Biomass estimates were on average underestimated by 26.30 ± 12.85% or overestimated by 32.83 ± 34.04%. The combinations of temperature and fish size that gave the highest frequencies of estimated and actual biomasses within 10% were the stockers at both 25 and 30 C (estimated biomass was within 10% of actual biomass on 75% occasions).

V. DISCUSSION

One of the biggest challenges in the pond culture of catfish is accurately knowing the quantity of fish in a pond. A commonly used method to estimate fish biomass is based on satiation feeding where biomass is estimated by dividing the amount of feed provided at satiation by the average percent body weight consumed by fish of a specific size class at a specific temperature. In this study, a number of issues were identified that affect the accuracy of estimating biomass based on satiation feeding and that only in a limited set of circumstances could actual biomass be accurately determined.

Quantity of feed given and consumed

Satiation is often determined using floating feed assuming that when a known quantity of feed is given and the quantity of feed still floating after a fixed period is subtracted from the quantity given then the difference between the two values is the quantity that was consumed. However, not all pellets in a "floating feed" actually float. In this study, five feed shipments were received from commercial suppliers and the percentage of feed that sank ranged from 12.8 to 34%. Unprasert et al. (1999) found that 60% of pellets from a 35% crude protein catfish feed remained buoyant after 30 minutes in 25 C water. In that study, one hundred pellets were placed into a water-filled beaker for 30 minutes. The quantity of pellets that remained afloat was then added up and expressed as a percentage of the total.

In the present study, it was not possible to tell whether or not the fish consumed the feed that sank. When the apparent feed consumption (feed/kg body weight) was calculated based upon the quantity of feed consumed/biomass harvested and compared to the actual quantity/kg consumed (determined by dissection), the two values were closely related using either the corrected apparent ($R^2 = 0.93$, $P < 0.0001$) or using the uncorrected apparent ($R^2 = 0.92$, $P < 0.0001$). The closeness of both values suggests that any feed (up to 34%) that may have sank may have been eaten (Fig. 2).

To accurately estimate feed consumption when feeding to satiation, it is necessary to know the quantity of uneaten feed. In this study, using floating feed in 0.04-ha ponds, it was possible to directly count the number of floating pellets remaining after 45 min after the first feed application. On several occasions when the feed response was weak, a large quantity of the feed provided would be leftover resulting in numerous pellets that needed to be counted. The quantity counted would be as high as 1,445 pellets. This was of concern for estimating satiation; however, when the results were analyzed the observed trend was that as the quantity of feed provided increased then percentage of feed left over actually decreased. This indicates that possible errors in counting excess feed minimally affected satiation estimates since the feed left over only represented a small fraction of the total feed provided. On average, 19.1 ± 24.7% of the feed given remained floating after 45 min, and 60.4% of the time the feed that remained floating was less than 10% of the original quantity of feed provided. Likewise, 66% of all the feed that remained floating was less than 20% of the original quantity of feed provided.

Satiation feeding has been used in several studies under varying protocols especially varying in the amount of time the fish were allowed to feed. How long a fish needs to become satiated may vary. It was observed that the large market fish were often slow to feed and some were still feeding 45 min after feed was first offered. In this study, additional feed was offered within a 10 min period after the first feed application if the fish appeared to be actively feeding. After 10 min, no additional feed was offered but fish were allowed to feed an additional 35 min on any feed that was still floating. In 94.3% of the trials, some floating feed was still evident at 45 min post-1st feeding. This period of time and quantity of feed given was adequate for all fish to have had the opportunity to feed; however, a significant portion of the fish in any population had not consumed feed. Several studies have varied in the amount of time used to determine satiation. Freeman (1998) fed channel catfish of mixed-sizes in ponds ad libitum over a 10-minute period while Prochaska (2000) fed channel catfish reared in ponds to satiation within a 20-min period. Evans (1995) fed market size channel catfish in ponds to satiation within a 45-minute period while Li et al. (2008) fed channel catfish reared in tanks to satiation for a 60-min period. Brett (1971) actually conducted an experiment to determine how long it would take for a fish to feed to satiation. The study determined satiation time to be about 43 ± 8 minutes for sockeye salmon (*Oncorhynchus nerka*) ranging in size from 2-350 g when provided Abernathy pellets at 15 C.

Percent body weight consumption

Actual vs. apparent feed consumption

The results indicated that the apparent and adjusted apparent techniques have a stronger linear relationship to actual feed consumption (R^2 = 0.923 and R^2 = 0.934 respectively) than the weekly apparent and adjusted weekly apparent techniques (R^2 = 0.789 and R^2 = 0.781 respectively). When the actual feed consumption was compared to the apparent feed consumption not corrected for percent sinking feed, the two estimates were within 10% of each other only 11.5% of the time. When the actual feed consumption and the adjusted apparent feed consumption were compared, the two estimates were within 10% of each other 30.8% of the time. Actual feed consumption and the weekly apparent feed consumption were within 10% of each other 15.4% of the time. Actual feed consumption and corrected weekly feed consumption were within 10% of each other 11.5% of the time. Therefore, it appears that it is better to use the corrected apparent satiation from the day of sampling rather than using the uncorrected apparent or a weekly average.

Factors influencing feed consumption

Average fish weight and temperature were the only parameters that significantly influenced feed consumption in this study when analyzed by multiple linear regression ($P < 0.0001$ and $P = 0.001$ respectively). Although hardness did not contribute significantly to the model at $P < 0.05$ ($P = 0.058$), it is difficult to say whether or not it truly influenced feed consumption.

Effect of fish size and temperature

Fish size appears to have a substantial influence on feed consumption with smaller fish consuming a greater percent body weight than larger fish over the range of temperatures tested (Table 4). Cacho (1984) found that smaller fish generally consumed more feed than the larger fish. In July, at water temperatures of about 28-30.7 C (measured at a depth of 1 m), 100.5 g fish consumed 3.36% body weight; 281.5 g fish, 2.65% body weight; and 624.0 g fish, 1.15% body weight. In August at about 26.9 to 29.1 C (measured at a depth of 1 m), 180.5 g fish consumed 2.44% body weight; 421.5 g fish, 1.62% body weight; and 666.5 g fish, 1.47% body weight. In September at about 24.6-28 C (measured at a depth of 1 m), 306.5 g fish consumed 1.58 % body weight;

615.0 g fish, 1.51 % body weight; and 924.0 g fish consumed 1.12 % body weight.

Green and Rawles (2010) found that for channel and hybrid catfish, the smaller fish consumed more on a percent biomass basis per day than the larger fish, with the hybrids exhibiting higher feed consumption than the channels. For instance, 0.163 kg and 0.508 kg channel catfish would consume 2.74% and 1.78% biomass, respectively, when using the regression equation provided in the paper ($y = -2.7832x + 3.1929$). On the other hand, equal size hybrids, based on the regression equation provided ($y = -3.2403x + 3.85$) would consume 3.32% and 2.20% biomass, respectively. They also found that the total quantity of feed eaten by the channel catfish was less than that of the hybrids (12,469 kg/ha vs. 16,581 kg/ha).

Accurately knowing average body weight is another source of variation when using satiation feeding to estimate biomass. As described earlier, the percent body weight consumed is body weight dependent; however, accurately knowing average body weight at any given point in time is a challenge. As fish grow they increase in size and size variation. Jiang (2005) found that NWAC 103 channel x D&B blue hybrids stocked at 31.8 ± 1.8 g grew to 635.0 ± 27.2 g (mean growth rate = 2.30 ± 0.07 g/day) when reared for 277 days from 1 and 2 March to 29 November – 2 December. Green and Engle (2004) found that channel catfish size variation increased substantially over a 98-day period starting with 0.26 ± 0.06 kg fish at a rate of 11,115 fish/ha. At harvest where the average final weight was 0.6 kg, the population structure was 17.7% <0.45 kg, 31.3% being 0.45-0.57 kg, and 29.3% of the population over > 0.68 kg. Cacho (1984) found that when 10-15 cm channel catfish were reared from 29-30 March to 19-21 September, size variation had increased considerably. At harvest (for the small fish that were fed the 26%

protein diet), 3.3% of the population was composed of 18-25 cm fish, 41.0% that were 25-32 cm, 53.0% being 32-39 cm, and 2.7% being 39-43 cm.

Fish are often sampled for average weights throughout experiments in order to determine fish growth. However, one problem with sampling is that the average weight from a fish sample may not be representative of the average weight of the population as a whole. Jiang (2005) found that at the end of the experiment mean sample weight and mean population weight were significantly different at $P < 0.05$ in three out of the 25 ponds used in the study.

Knowing average weights at any given time can be a challenge in single batch ponds, but it can be even more challenging in a multiple-batch system. After several harvest and restocking cycles, a pond using the multiple-batch system possesses a wide range of size distributions ranging from fingerlings to large market fish. This makes it extremely difficult to know fish abundance and size distribution in the ponds. To use satiation feeding to estimate biomass one would need to know the frequency of each size class as well as the average weight for each size class. The change in fish size distribution was described by Busch (1986). He initially stocked channel catfish in ponds with size classes that were on average <0.34 kg (<0.75 lbs), 0.34-0.63 kg (0.75-1.4 lbs), and 0.68-1.31 kg (1.5-2.9 lbs) of which each size class made up about 15.1%, 60.7%, and 24.2% of the pond, respectively. When ponds were harvested at the end of the study the average size distribution was about 0% for fish <0.34 kg (<0.75 lbs), 5.9% for fish 0.34-0.63 kg (0.75-1.4 lbs), 40.5% for fish 0.68-1.31 kg (1.5-2.9 lbs), 34.2% for fish 1.36-1.77 kg (3.0-3.9 lbs), and 19.4% for fish greater or equal than 1.81 kg (4 lbs). Tucker et al. (1993) conducted a 3-year experiment comparing the production features of both single-batch and multiple-batch ponds at two fish stocking rates (11,120 fish/ha and 19,770 fish/ha). The ponds were stocked with channel catfish that varied from 25 to 50 g. At the end of the 3-year study when ponds were harvested, the multiple-batch system had a greater percentage of larger fish than the single-batch system. In ponds stocked at 19,770 fish/ha, the size distributions in the single batch system at harvest were: 17% for fish <0.34 kg, 72% for fish 0.34-1.12 kg, 9% for fish 1.13-1.81 kg, and 2% of fish >1.81 kg. In the multiple batch system at 19,770 fish/ha, the size distribution was 9% of fish <0.34 kg, 71% for fish 0.34-1.12 kg, 15% for fish 1.13-1.81 kg, and 5% of fish > 1.81 kg.

Water temperature is one of the key factors presiding over biological responses in poikilotherm animals such as fish (Kestemont and Baras 2001) and was the primary environmental factor affecting feed consumption rates in this study. In some cases, consumption increased as temperature increased, but there was not always a consistent trend over the temperature range tested. Feed consumption by stockers and large market fish remained similar at 25 C and 30 C. Fingerlings and market size fish at 20 C and 25 C consumed similar rates of feed, while at 30 C consumed a greater rate of feed. Buentello et al. (2000) found that feed consumption, for channel catfish stocked at 15.0 ± 0.23 g in aquaria at different dissolved oxygen concentrations, increased when water temperature was elevated from 15.7 to 31.7 C. Li et al. (2008) observed that feed intake differed among channel catfish placed in tanks over a nine-week period at temperatures of about 27, 21, and 17 C. At the beginning of the study the channel catfish weighed 9.6 ± 0.1 g. Feed with various concentrations of fishmeal was also provided to the fish in the study. Feed intake was reported as 90% dry matter. On average, fish consumed 13.4 g/fish at 17 C, 41.4g/fish at 21 C, and 120 g/fish at 27 C.

Wagner (1998) found that hybrid catfish (stocked at a mean initial weight of 95 g and harvested at a mean ending weight of 212 g) when fed to satiation in earthen ponds ate 3.18% body weight per day at temperatures between 23 to 27 C, while they only ate 0.38% body weight per day at pond temperatures between 15 and 18 C. The estimated fish biomass on any particular day was derived from the actual biomass at the end of the experiment, FCR, and the quantity of feed consumed each day.

Q_{10} temperature coefficients were generated in the present study to see if a specific size class was more sensitive to a change in temperature than the others. The Q_{10} temperature coefficient in this study (from 20 to 30 C) based on the mean feed consumption (% body weight consumed) was 1.57 for the fingerlings, 1.30 for the stockers, 2.9 for the market fish, and 2.45 for the large market fish. This indicates that the market fish was the size class in which feed consumption was most dependant on temperature. The size class where feed consumption was least dependent on temperature was the stockers. When small fish (fingerlings and stockers) and large fish (market and large market fish) were compared, the larger fish yielded a higher Q_{10} temperature coefficient than the smaller fish (2.87 vs. 1.44, respectively). Therefore, one can conclude from this experiment that larger fish generally appear to be influenced more by changes in temperature than the smaller fish. This is consistent with Cacho (1984) who observed that feed consumption in large fish appeared to be influenced more by variations in DO and temperature than smaller fish. He also noted that the recovery time from sampling stress was faster for the smaller fish than for the larger fish. The results of the present experiment are also in agreement with Rao and Bullock (1954) who compared several studies that documented Q_{10} values for various poikilothermic species. They concluded that the Q_{10} temperature coefficient generally increased as an organism became larger as long as that organism was functioning within its ordinary physiological gamut of temperatures. Morris (1962) found that in the cichlid *Aequidens portalegrensis*, the larger fish tended to have higher Q_{10} temperature coefficients than the smaller fish with respect to oxygen consumption.

The magnitude of change by each size class as a function of temperature is given in Fig. 3 where consumption at 25 C is used as the baseline consumption. When water temperature decreased from 25 to 15 C, mean feed consumption declined over 96% for all size classes. The mean feed consumption decline from the 25 to 20 C was -5.0% for the fingerlings, -24.6% for the stockers, -33.0% for the market fish, and -64.5 % for the large market fish. When water temperature increased from 25 C to 30 C mean feed consumption decreased slightly for the stockers (-2.1%) and large market fish (-14.8%) while it increased for fingerlings (49.0%) and market size fish (95.9%). Expressing the effect of temperature as a magnitude change relative to a base line temperature, in this case 25 C, also demonstrated how smaller fish were less affected by temperature than larger fish when water temperatures were decreased below 25 C. However, this size trend was not observed when the temperature was raised from 25 C to 30 C since there was no significant difference in feed consumption between both 25 C and 30 C treatments for the stockers and large market fish.

Effect of season

In this study, feed consumption appeared to be heavily influenced by season at 25 C and 30 C ($P < 0.0001$). For example, at 25 C in the spring, the mean feed consumption for all size classes was 2.05 ± 1.38 % while in the fall at 25 C the feed consumption was

1.02 ± 1.45 %. The direction of the temperature change may have been a factor as the spring temperatures represent a rising temperature while the autumn temperature represents a falling temperature. Anthouard et al. (1994) noted that when water temperature rose sharply, right after an episode of cooler water temperatures, European catfish *Silurus glanis* exhibited an elevated feed response.

Another environmental parameter that changes with season is photoperiod. Several studies have documented the effect of photoperiod under controlled conditions on fish feed consumption. For instance, Petit et al. (2003) compared feed consumption in 3.5 g largemouth bass (*Micropterus salmoides*) stocked in aquaria when assigned to a photoperiod of 12 light hours : 12 dark hours and a photoperiod of 24 light hours : 0 dark hours for 12 weeks. The results revealed fish exposed to the photoperiod of 24 hours of light : 0 hours of dark had a higher feed intake than the fish designated to the 12 light hours : 12 dark hour photoperiod. Ergün et al. (2003) found that that feed consumption feed consumption in the 24 light hours : 0 dark hours photoperiod and the 16 light hours : 8 dark hours photoperiod was statistically greater than feed consumption in the natural photoperiod for fingerling rainbow trout (*Oncorhynchus mykiss*).

In the present study, feed consumption during spring/early summer was not affected by the increasing photoperiod ($R^2 = 0.033$, $P = 0.430$). However, during late summer/fall there appeared to be a linear association between feed consumption and day length resulting in decreased feed consumption as day length decreased ($R^2 = 0.173$, $P = 0.044$). However, this decrease in feed consumption was most likely caused by the decreasing water temperature and not the shorter days themselves.

Effect of other environmental parameters

None of the environmental parameters, except temperature, appeared to have a substantial impact on feed consumption. It has been well documented in the literature that low dissolved oxygen concentrations substantially depress feed consumption in channel catfish (Andrews et al. 1973; Torrans 2005). Buentello et al. (2000) found that dissolved oxygen levels below about 70% air saturation substantially decreased feed consumption in channel catfish. Dissolved oxygen concentrations in the present study were on average 90.3 ± 13.7 % saturation during the time of sampling; so, they did not play a major role in depressing feed consumption.

Variability in feed consumption among individual fish and ponds

One possible contributor to the variability in feed consumption could have been the fact that fish still contained a portion of feed fed to them during the prior days in their digestive tract. However, this is unlikely since fish in this particular experiment were fasted for one day at temperatures of 20 C and above and were fasted for two days during the 15 C temperature treatment. Upon dissection it was often noted that there were some contents in the intestinal tracts of the fish but pellets found in the stomach appeared to be undigested. It is therefore possible that some of the feed prior to fasting may have remained in the stomach of the fish on the day of sampling, but the amount would have been minimal. Shrable et al. (1969) found that the percentage of dry feed that was left only in the stomach of fish 24 hours after feeding was 19.67% at 15.5 C, 5.45% at 21.1 C, 2.67% at 26.6 C, and 0.89% at 29.4 C.

Another factor influencing estimation of percent consumption is the variation in consumption among individual fish particularly the percent of fish not consuming feed. Feeding was particularly slow at 15 C with 96% of the fish (all sizes) not having feed in the stomach when examined. The percentage of fish that actually fed was highest at 30 C (Table 5) where 100% of the stockers were feeding. However, for the other classes there was a portion of the population that was still not feeding. The magnitude of the variability for feed consumption (% body weight) for individual fish in this study differed by both size and temperature (Figs. 4-5, 6-9). The coefficient of variation in mean feed consumption was generally greater the larger the fish size class. The fingerlings, stocker, market, and large-market fish at all temperatures had coefficients of variation of 79.8, 68.2, 117.8, and 175%, respectively. Likewise, the coefficient of variation was greater the lower the temperature treatment. When all size classes of fish were grouped into the 15 C, 20 C, 25 C, and 30 C temperature treatments, the coefficients of variations in mean feed consumption was 366.7, 117.5, 98, and 76.9% respectively. The most consistent results were the stockers at 30 C, which had a coefficient of variation of 34.4%. The means and modes for feed consumption of all fish size classes at each temperature were compared to observe the impact of the non-feeding fish on feed consumption (Table 7). The mode was less than or equal to the mean for all sizes at all temperatures except for the fingerlings at 30 C. When the non-feeding fish were removed for the fingerlings at 30 C, the mode was still greater than the mean.

This variation among individual fish is consistent with other studies such as Wang et al. (1998) who also found a large amount of inter-individual variability in food intake when studying hybrid sunfish (*Lepomis cyanellus* x *Lepomis macrochirus*). In the study, fish were raised individually at 24 ± 1 C in a recirculating system and were fed to satiation with mealworms (*Tenebrio molitor*) that were consistent in size. Initial weights of the fish ranged from 9.8 g to 18.1 g and they were reared for a 112-day period. The average percent body weight consumed per day was significantly different among fish and varied from 1.06-1.59 % body weight per day. Coefficients of variation among individual fish varied from 60.8 to 113.9 %.

Tyler and Bolduc (2008) found that there was significant variation in feed consumption among individual fish. Rainbow trout (*Oncorhynchus mykiss*) initially weighing 14.45 ± 3.016 g were distributed individually into 5-L buckets (covered with mesh) that were then placed into holding tanks at a constant temperature. Fish were fed a pre-weighed ration in excess and after one hour any uneaten feed was removed, dried, and the weight of dry uneaten feed was deducted from the initial quantity provided to determine the quantity of feed ingested. This procedure was performed twice a day. Feeding data was obtained for each fish at 7, 11, 15, and 19 C. Results using ANCOVA found that individual fish variation significantly influenced feed consumption ($P \leq 0.001$).

Feed response varied among ponds stocked with similar size fish at a common temperature and managed the same. When the actual percent body weight consumed for the two replicates within each specific sampling period were compared to each other, in 25 cases only 12% of the time were the replicate within 10% of each other. On average the two replicates in each treatment were within 76.7 ± 64.3% of each other. Factors contributing to this variation could not be identified based on the parameters monitored. Tackett et al. (1988) found that day-to-day feed intake in channel catfish differed on average 61% for 0.26 kg (0.57 lb) fish stocked at 897 kg/ha (200 lb/0.25 acre) and 59% for 0.04 kg (0.09 lb) fish stocked at 336 kg/ha (75 lb/0.25 acre). They also found that the difference in day-to-day feed consumption ranged from 0 to 1,450% for the 0.04 kg (0.09

lb) fish stocked at 336 kg/ha (75 lb/0.25 acre). Evans (1995) also reported a substantial amount of daily variation in feed consumption by 569-909 g (stocking weight) channel catfish fed to satiation in earthen ponds. The average difference in day-to-day feed consumption was 27.8% for ponds that were fed to satiation every day, ranging from 3 to 83%. In the present study, when fish were fed to satiation for three or more days prior to sampling, daily variation in a given pond was 38.2 ± 111.3 % and ranged from 0.0 to 1,615.7% (for fish of all sizes and temperatures) (Table 6).

All in all, feed consumption was quite variable throughout the study (Table 4). Feed consumption was heavily influenced by both fish size and temperature (Figs. 4-5, 6-9) but not much by water quality parameters and meteorological conditions. In the study, there were specific situations when feed consumption was more consistent. The most consistent feed response (lowest coefficient of variation) throughout the entire study was the stockers at 30 C (CV = 34.4%).

Factors affecting biomass estimations

Biomass estimations based on satiation feeding are dependent on accurate estimations of percent body weight consumed, the quantity of feed given and the quantity of feed not consumed. As discussed earlier, actual feed consumption varies as a function of fish size and temperature and is variable among ponds even under the same set of conditions. Biomass estimations were extrapolated from actual percent body weight consumed and the quantity of feed provided during the day of sampling using both the unadjusted and adjusted (assuming only the fraction that floated was consumed) satiation estimates. Biomass was then converted to a standing crop as kg/ha. When the corrected consumption estimate was included in the satiation estimate, the accuracy of the comparison to the actual standing crop improved substantially. When actual standing crop was compared to apparent standing crop estimated by satiation, using actual feed consumption not corrected for percent sinking, the two estimates were only within 5% of each other 5.8% of the time and within 10% of each other 11.5% of the time (Tables 8-9). Correcting the satiation estimate considering only the feed that floated substantially improved the frequency of occurrences where actual and estimated standing crops were within 5% of each other to 23.1% of the time, and within 10% of each other on 30.8% of the time (Table 10-11). Using the mode to estimate biomass (also compared as kg/ha) did not improve biomass estimates. Only 15.6% of the estimated standing crops were within 10% of the actual standing crop when the mode was used to calculate biomass assuming that only the floating feed was consumed.

Despite the improvement in standing crop estimates, the adjusted technique was only effective in estimating 30.8% of the cases within 10% of the actual standing crop. Therefore, the technique does not appear to be very promising on a commercial scale where having tight control of the inventory is vital for the success and profitability of the aquaculture operation. Engle et al. (1998) also attempted to estimate biomass and compare it to the actual biomass. However, the study used a depletion technique for its inventory assessments. In this technique, a seine was passed through each pond (at least three hauls per pond) in order to collect fish so a number and weight could be assessed. The fish from each seining period were taken out of the pond and the left over biomass was determined by means of a mathematical depletion model. This biomass estimate was then compared to the actual biomass of the pond (after a total harvest of the pond) to evaluate the accuracy of the technique.

Results of the experimental pond research revealed that the estimated fish weights varied when compared to the actual fish weights by -0.1%, 0%, and -7.7% (Engle et al. 1998). Results from the commercial pond component of the experiment revealed that the estimated fish weights varied when compared to the actual fish weights by -3.5% to -6.1% for two ponds in 1995 and varied by -28.4 to 33.3% for 17 ponds in 1996. For the 17 ponds in 1996, 59% of the estimates were ± 10% of the actual fish weight while 82% of the estimates were ± 15% of the actual fish weight. The results reveal that this technique could assess biomass accurately if all of the ponds from the farm are analyzed collectively. However, when it comes to determining biomass for a single pond, the technique lacks precision.

When biomass estimations based on satiation feeding takes into consideration the effect of fish size and temperature, the frequency of more accurate estimates improves to where biomass estimations based on satiation feeding may be appropriate under certain circumstances. Independent of fish size, the 30 C temperature treatment had the highest frequency of occurrences out of all temperatures. At 30 C, 40% of the biomass estimates were within 5% of the actual biomass. Similarly, 46.7% of the biomass estimates fell within 10% of the actual biomass.

Fish size affected how close estimated biomasses were to actual biomasses. Over all temperature ranges, using the feed input adjusted for % sinking, estimated biomasses for fish in the fingerling, stocker, and market size categories were within 5% of the actual biomass on 28.6, 33.3, and 28.6% of the occasions, respectively, while no estimates for ponds of large market fish were within 5% of actual. Estimated biomasses were within 10% of actual on 42.9% of the occasions for fingerlings, 50% for stockers and 28.6% of the occasions for market-size fish, and none of estimates from ponds with large market fish within 10% of the actual. The combinations of temperature and fish size that gave the overall highest frequencies of estimated biomass being within 10% of actual biomass was for stockers at both 25 and 30 C where the estimates were within 10% of actual 75% of the time when the feed consumption estimate was adjusted for the % sinking feed (Tables 10-11).

VI. CONCLUSIONS

Overall, the present study revealed that using satiation feeding to estimate biomass is only effective under certain conditions. However, in most circumstances satiation feeding is not an accurate way to estimate biomass. The first condition requires an accurate estimate of quantity of feed consumed by the fish. For this condition to hold true all of feed must float and not sink to the bottom. When feed is no longer available for visual inspection at the surface of the pond, one can only speculate whether or not the sunken feed was actually consumed. In this particular study, this issue was addressed by determining the percentage of feed that floated beforehand and making assumption that the fish only consumed the fraction that floated. This correction factor substantially improved the accuracy of the biomass estimations.

The next condition that needs to be satisfied is the accuracy and consistency of percent body weight consumed by the fish. This was heavily dependent on both fish size and temperature. In general, feed consumption increased as a function of temperature. Feed consumption was least variable at 30 C. Usually, feed consumption also decreased as a function of fish size. However, the stockers were the least variable of all the size classes. The fish size and temperature treatment with the most consistent feed response throughout the entire study was the stockers at 30 C. The combinations of temperature and fish size that gave the highest frequencies of estimated and actual biomasses within 10% were the stockers at both 25 and 30 C (estimated biomass was within 10% of actual biomass on 75% occasions). Therefore, it is suggested that this technique be used only in ponds where fish are feeding actively and consistently, but overall it does not appear to be very promising on a commercial scale.

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VIII. TABLES

Table 1. Mean water quality and meteorological parameters the day of sampling for all fish sizes and temperatures for hybrid catfish (channel x blue) sampled to determine feed consumption.

Parameter	Mean ± SD
DO (mg/L)	7.5 ± 1.3
DO (% saturation)	90.3 ± 13.7
pH	7.2 ± 0.47
Total ammonia (mg/L)	0.2 ± 0.1
Alkalinity (mg/L)	47.7 ± 8.9
Hardness (mg/L)	39.2 ± 7.0
Barometric pressure (cm)	76.5 ± 0.36
Wind speed (km/h)	25.4 ± 7.6
Precipitation (cm)	0.18 ± 0.64
Solar radiation (Watt-hours per m^2)	4,750.1 ± 1,858.3

Table 2. Actual percent body weight consumed determined from the fish dissections vs. apparent satiation based on the total quantity of feed given/total fish biomass, for fish of all sizes at all temperatures tested.

Parameter	Mean and SD*	n
[a]Actual	1.38 ± 1.32	53
[b]Uncorrected	1.68 ± 1.60	53
[c]Corrected	1.29 ± 1.20	53
[d]Weekly	1.55 ± 1.41	53
[e]Corrected weekly	1.19 ± 1.07	53

[a]Actual = actual % body weight consumed based on the fish dissections from the 25 fish sample

[b]Uncorrected = uncorrected apparent % body weight consumed based on the pond biomass

[c]Corrected = corrected apparent % body weight consumed based on the pond biomass

[d]Weekly = weekly apparent % body weight consumed based on the pond biomass

[e]Corrected weekly = corrected weekly apparent % body weight consumed based on the pond biomass

*All values within a parameter column were not significantly different ($P > 0.05$)

Table 3. Actual percent body weight consumed determined from the fish dissections vs. apparent satiation based on total pond biomass for a specific fish size at a specific temperature among ponds.

Fish size	Water temperature	Actual[a]	Uncorrected[b]	Corrected[c]	Weekly[d]	Corrected weekly[e]	n
Fingerling	15 C	0.07 ± 0.06	0.04 ± 0.01	0.03 ± 0.01	0.05 ± 0.01	0.04 ± 0.00	2
	20 C	1.92 ± 1.03	2.31 ± 1.39	1.76 ± 0.96	2.69 ± 0.39	2.13 ± 0.20	4
	25 C	2.02 ± 1.36	2.57 ± 1.58	1.98 ± 1.15	2.15 ± 1.20	1.66 ± 0.83	4
	30 C	3.01 ± 1.33	4.07 ± 1.39	3.04 ± 0.92	4.04 ± 0.38	3.05 ± 0.21	4
Stocker	15 C	0.05 ± 0.07	0.05 ± 0.05	0.03 ± 0.03	0.11 ± 0.11	0.07 ± 0.07	2
	20 C	2.15 ± 1.60	1.51 ± 0.70	1.27 ± 0.67	1.48 ± 0.86	1.24 ± 0.79	3
	25 C	2.85 ± 0.11	3.29 ± 0.46	2.62 ± 0.39	2.31 ± 0.88	1.79 ± 0.52	4
	30 C	2.79 ± 0.39	3.62 ± 0.78	2.71 ± 0.47	3.51 ± 0.16	2.65 ± 0.11	4
Market	15 C	0.00 ± 0.00	0.01 ± 0.0	0.00 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	2
	20 C	0.65 ± 0.45	0.75 ± 0.56	0.60 ± 0.48	0.72 ± 0.30	0.57 ± 0.25	4
	25 C	0.97 ± 1.21	1.17 ± 1.35	0.85 ± 0.98	1.01 ± 1.14	0.73 ± 0.83	4
	30 C	1.90 ± 0.82	2.46 ± 0.86	1.86 ± 0.65	1.98 ± 0.91	1.51 ± 0.73	4
Large market	15 C	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	2
	20 C	0.08 ± 0.12	0.10 ± 0.14	0.07 ± 0.10	0.21 ± 0.10	0.17 ± 0.08	3
	25 C	0.31 ± 0.39	0.46 ± 0.68	0.34 ± 0.49	0.45 ± 0.73	0.33 ± 0.53	4
	30 C	0.27 ± 0.03	0.42 ± 0.06	0.31 ± 0.04	0.42 ± 0.20	0.32 ± 0.16	3

[a]Actual = actual % body weight consumed based on the fish dissections from the 25 fish sample

[b]Uncorrected = uncorrected apparent % body weight consumed based on the pond biomass

[c]Corrected = corrected apparent % body weight consumed based on the pond biomass

[d]Weekly = weekly apparent % body weight consumed based on the pond biomass

[e]Corrected weekly = corrected weekly apparent % body weight consumed based on the pond biomass

Table 4. Mean *pooled feed consumption (% BW) determined from the dissections for four size classes of fish at four temperatures.

Size	15 C	20 C	25 C	30 C
Fingerling	0.07 ± 0.13^{aw}	1.92 ± 1.22^{bw}	2.02 ± 1.47^{bw}	3.01 ± 1.48^{cw}
Stocker	0.05 ± 0.16^{awx}	2.15 ± 1.65^{bw}	2.85 ± 1.20^{cx}	2.79 ± 0.96^{cw}
Market	0.00 ± 0.02^{ax}	0.65 ± 0.76^{bx}	0.97 ± 1.22^{by}	1.90 ± 1.24^{cx}
Large Market	0.00 ± 0.01^{ax}	0.11 ± 0.24^{ay}	0.31 ± 0.47^{bz}	0.27 ± 0.32^{by}

Common superscript letters (a-c) within a parameter row indicate no significant difference ($P > 0.05$) among different temperatures for a common size class. Common superscript letters (w-z) within a parameter column indicate no significant difference ($P > 0.05$) among different size classes for a given temperature

* Pooled feed consumption was based on the feed consumption from each individual fish when all fish from replicate ponds in a given treatment were pooled together (see table 5 for n). The mean feed consumption from the individual fish pooled together for each treatment were then compared by ANOVA.

Table 5. Percentage of non-feeding fish for each size class and temperature from the sample of dissected fish. Non-feeding fish were classified as fish that consumed less than 0.25 % body weight.

Temperature	Size	*Non-feeding fish (% of the population)	[a]Mean % BW consumed (*pooled)	n
15 C	Fingerling	90.2	0.07 ± 0.13	51
15 C	Stocker	94.1	0.05 ± 0.16	51
15 C	Market	100.0	0.00 ± 0.02	50
15 C	Large	100.0	0.00 ± 0.01	50
20 C	Fingerling	12.1	1.92 ± 1.22	100
20 C	Stocker	12.0	2.15 ± 1.65	75
20 C	Market	43.0	0.65 ± 0.76	100
20 C	Large	84.0	0.11 ± 0.24	100
25 C	Fingerling	22.0	2.02 ± 1.47	100
25 C	Stocker	2.0	2.85 ± 1.20	100
25 C	Market	52.0	0.97 ± 1.22	100
25 C	Large	67.0	0.31 ± 0.47	100
30 C	Fingerling	2.0	3.01 ± 1.48	100
30 C	Stocker	0.0	2.79 ± 0.96	99
30 C	Market	10.0	1.90 ± 1.24	100
30 C	Large	65.0	0.27 ± 0.32	100

[a]For all fish sampled, including the non-feeders

*Pooled feed consumption and % non-feeding fish was based on the feed consumption from each individual fish when all fish from replicate ponds in a given treatment were pooled together. The mean feed consumption from the individual fish pooled together for each treatment was then generated.

Table 6. "Daily difference"[a] in feed consumption for a common fish size and temperature for ponds fed 3+ days to satiation.

Size	Temperature (C)	Mean and SD	Range (%)
Fingerling	15	29.8 ± 26.4	1.4-84.7
Fingerling	20	15.8 ± 20.9	0.0-107.1
Fingerling	25	32.6 ± 44.3	0.1 to 270.2
Fingerling	30	23.1 ± 24.4	1.7-149.9
Stocker	15	47.8 ± 41.1	1.3-154.3
Stocker	20	95.1 ± 311.0	1.4-1,375.2
Stocker	25	36.9 ± 42.7	0.0-174.5
Stocker	30	23.1 ± 58.5	0.0-381.9
Market	15	62.7 ± 53.3	3.9-176.1
Market	20	19.8 ± 26.6	0-103.0
Market	25	28.7 ± 37.2	0-230.8
Market	30	19.3 ± 19.4	0-71.8
Large market	15	24.8 ± 15.9	3.3-59.3
Large market	20	37.4 ± 31.2	0.2-109.9
Large market	25	129.6 ± 320.1	0.0-1,615.7
Large market	30	63.0 ± 167.8	0.6-899.5

[a] % "daily difference" in feed consumption = 100 x (quantity consumed - quantity consumed the day prior) / quantity of feed consumed the day prior. The term "daily difference" was described by Tackett et al. (1988) as well as Evans (1995).

Table 7. *Pooled modal and mean feed consumptions as a function of fish size and water temperature. Modes are presented in 0.25 intervals as % body weight consumed.

		% Body weight consumed			
		All fish (feeding and non-feeding)		Only feeding fish	
Temperature	Size	Mean	Mode (s)	Mean	Mode (s)
15 C	Fingerling	0.07 ± 0.13	0-0.25	0.41 ± 0.09	0.25-0.5
15 C	Stocker	0.05 ± 0.16	0-0.25	0.55 ± 0.46	0.25-0.5
15 C	Market	0.00 ± 0.02	0-0.25	None fed	None fed
15 C	Large	0.00 ± 0.01	0-0.25	None fed	None fed
20 C	Fingerling	1.92 ± 1.22	0-0.25	2.16 ± 1.07	3-3.25
20 C	Stocker	2.15 ± 1.65	0-0.25	2.43 ± 1.56	0.75-1, 1.5-1.75
20 C	Market	0.65 ± 0.76	0-0.25	1.09 ± 0.73	0.25-0.5
20 C	Large	0.11 ± 0.24	0-0.25	0.53 ± 0.39	0.25-0.5
25 C	Fingerling	2.02 ± 1.47	0-0.25	2.58 ± 1.14	1.75-2.0, 2.5-2.75
25 C	Stocker	2.85 ± 1.20	2.5-2.75	2.91 ± 1.15	2.5-2.75
25 C	Market	0.97 ± 1.22	0-0.25	1.99 ± 1.03	1.75-2
25 C	Large	0.31 ± 0.47	0-0.25	0.84 ± 0.48	0.25-0.5
30 C	Fingerling	3.01 ± 1.48	4-4.25	3.06 ± 1.44	4-4.25
30 C	Stocker	2.79 ± 0.96	2.75-3	2.79 ± 0.96	2.75-3
30 C	Market	1.90 ± 1.24	0-0.25, 0.25-0.5	2.10 ± 1.15	0.25-0.5
30 C	Large	0.27 ± 0.32	0-0.25	0.58 ± 0.36	0.25-0.5

*Pooled feed consumption was based on the feed consumption from each individual fish when all fish from replicate ponds in a given treatment were pooled together.

Table 8. Standing crop estimates for the small fish (fingerlings and stockers) assuming the fish consumed all the feed that was given. Biomass was estimated by dividing the quantity of feed provided by the actual % body weight consumed as determined from the dissections. The biomass was then expressed as a standing crop (kg/ha). This estimated standing crop was then compared to the actual standing crop of the pond from the day of harvest. The percent difference between the two was determined using the actual standing crop as the standard.

			Fish standing crop (kg/ha)			
Pond	Size class	Temperature	Actual	Estimated	Difference (%)	
E26	Fingerling	15 C	377	119	-68.4	
E5	Fingerling	20 C	288	271	-6.1	**
E6	Fingerling	20 C	287	311	8.4	**
E9	Fingerling	25 C	281	335	19.5	
E5	Fingerling	25 C	311	381	22.7	
E29	Fingerling	30 C	352	435	23.4	
E4	Fingerling	20 C	216	267	23.6	
E4	Fingerling	30 C	364	476	30.9	
E7	Fingerling	20 C	233	305	31.0	
E5	Fingerling	30 C	346	466	34.5	
E28	Fingerling	25 C	306	417	36.0	
E3	Fingerling	15 C	284	476	67.7	
E9	Fingerling	30 C	351	629	79.2	
E8	Fingerling	25 C	257	723	181.2	
E8	Stocker	20 C	671	385	-42.6	
E6	Stocker	15 C	623	521	-16.3	
E9	Stocker	20 C	570	502	-11.8	
E1	Stocker	20 C	440	418	-5.1	**
E26	Stocker	25 C	530	540	1.9	*
E29	Stocker	30 C	648	717	10.7	
E26	Stocker	25 C	567	631	11.4	
E2	Stocker	25 C	727	852	17.2	
E8	Stocker	30 C	631	790	25.1	
E9	Stocker	30 C	887	1,158	30.5	
E1	Stocker	25 C	500	653	30.6	
E8	Stocker	30 C	933	1,394	49.5	

*Estimated standing crop is within 5% of the actual standing crop

**Estimated standing crop is within 10% of the actual standing crop

Table 9. Standing crop estimates for the large fish (market and large market fish) assuming the fish consumed all the feed that was given. Biomass was estimated by dividing the quantity of feed provided by the actual % body weight consumed as determined from the dissections. The biomass was then expressed as a standing crop (kg/ha). This estimated standing crop was then compared to the actual standing crop of the pond from the day of harvest. The percent difference between the two was determined using the actual standing crop as the standard.

			Fish standing crop (kg/ha)			
Pond	Size class	Temperature	Actual	Estimated	Difference (%)	
E29	Large	25 C	1,926	1,404	-27.1	
E26	Large	20 C	2,392	1,767	-26.1	
E2	Large	15 C	2,206	2,175	-1.4	*
E5	Large	25 C	2,825	3,352	18.7	
E3	Large	20 C	2,137	2,635	23.3	
E6	Large	25 C	2,309	2,947	27.7	
E5	Large	30 C	3,182	4,474	40.6	
E6	Large	30 C	2,339	3,719	59.0	
E3	Large	30 C	2,410	3,889	61.4	
E3	Large	25 C	1,875	3,167	68.9	
E1	Large	15 C	3,270	7,359	125.0	
E4	Large	20 C	2,273	5,323	134.2	
E7	Market	25 C	2,537	1,026	-59.6	
E5	Market	15 C	2,341	1,887	-19.4	
E25	Market	20 C	2,594	2,124	-18.1	
E2	Market	25 C	1,297	1,327	2.3	*
E10	Market	30 C	2,692	3,264	21.2	
E25	Market	30 C	2,149	2,702	25.7	
E1	Market	20 C	2,759	3,587	30.0	
E25	Market	30 C	2,266	2,955	30.4	
E6	Market	20 C	1,758	2,331	32.6	
E9	Market	15 C	2,758	4,360	58.1	
E10	Market	30 C	1,794	2,872	60.1	
E6	Market	25 C	1,703	2,761	62.2	
E2	Market	20 C	2,493	6,063	143.2	
E3	Market	25 C	2,629	9,887	276.1	

*Estimated standing crop is within 5% of the actual standing crop

**Estimated standing crop is within 10% of the actual standing crop

Table 10. Standing crop estimates for the small fish (fingerlings and stockers) assuming fish only consumed the feed that floated. Biomass was estimated by dividing the quantity of feed provided by the actual % body weight consumed as determined from the dissections. The biomass was then expressed as a standing crop (kg/ha). This estimated standing crop was then compared to the actual standing crop of the pond from the day of harvest. The percent difference between the two was determined using the actual standing crop as the standard.

			Fish standing crop (kg/ha)			
Pond	Size class	Temperature	Actual	Estimated	Difference (%)	
E26	Fingerling	15 C	377	79	-79.2	
E5	Fingerling	20 C	288	236	-18.1	
E9	Fingerling	25 C	281	243	-13.4	
E4	Fingerling	20 C	216	193	-10.4	
E29	Fingerling	30 C	352	317	-10.1	
E6	Fingerling	20 C	287	271	-5.4	**
E7	Fingerling	20 C	233	221	-5.0	*
E5	Fingerling	30 C	346	339	-2.1	*
E28	Fingerling	25 C	306	302	-1.4	*
E4	Fingerling	30 C	364	373	2.6	*
E5	Fingerling	25 C	311	333	7.0	**
E3	Fingerling	15 C	284	314	10.7	
E9	Fingerling	30 C	351	493	40.5	
E8	Fingerling	25 C	257	631	145.2	
E8	Stocker	20 C	671	336	-49.9	
E6	Stocker	15 C	623	344	-44.8	
E1	Stocker	20 C	440	303	-31.2	
E26	Stocker	25 C	530	392	-26.1	
E9	Stocker	20 C	570	438	-23.1	
E29	Stocker	30 C	648	562	-13.2	
E1	Stocker	25 C	500	473	-5.3	**
E9	Stocker	30 C	887	843	-5.0	*
E26	Stocker	25 C	567	551	-2.8	*
E8	Stocker	30 C	631	619	-1.9	*
E2	Stocker	25 C	727	743	2.2	*
E8	Stocker	30 C	933	1,015	8.8	**

*Estimated standing crop is within 5% of the actual standing crop

**Estimated standing crop is within 10% of the actual standing crop

Table 11. Standing crop estimates for the large fish (market and large market fish) assuming fish only consumed the feed that floated. Biomass was estimated by dividing the quantity of feed provided by the actual % body weight consumed as determined from the dissections. The biomass was then expressed as a standing crop (kg/ha). This estimated standing crop was then compared to the actual standing crop of the pond from the day of harvest. The percent difference between the two was determined using the actual standing crop as the standard.

			Fish standing crop (kg/ha)			
Pond	Size class	Temperature	Actual	Estimated	Difference (%)	
E7	Market	25 C	2,537	895	-64.7	
E5	Market	15 C	2,341	1,245	-46.8	
E25	Market	20 C	2,594	1,540	-40.6	
E2	Market	25 C	1,297	962	-25.8	
E10	Market	30 C	2,692	2,376	-11.7	
E25	Market	30 C	2,266	2,152	-5.0	*
E6	Market	20 C	1,758	1,690	-3.9	*
E25	Market	30 C	2,149	2,118	-1.4	*
E9	Market	15 C	2,758	2,878	4.4	*
E1	Market	20 C	2,759	3,128	13.4	
E6	Market	25 C	1,703	2,002	17.6	
E10	Market	30 C	1,794	2,251	25.5	
E2	Market	20 C	2,493	5,287	112.0	
E3	Market	25 C	2,629	8,622	228.0	
E29	Large	25 C	1,926	1,224	-36.4	
E26	Large	20 C	2,392	1,541	-35.6	
E2	Large	15 C	2,206	1,435	-34.9	
E5	Large	25 C	2,825	2,430	-14.0	
E3	Large	20 C	2,137	1,910	-10.6	
E5	Large	30 C	3,182	3,507	10.2	
E6	Large	25 C	2,309	2,570	11.3	
E6	Large	30 C	2,339	2,707	15.7	
E3	Large	30 C	2,410	2,832	17.5	
E3	Large	25 C	1,875	2,296	22.4	
E1	Large	15 C	3,270	4,857	48.5	
E4	Large	20 C	2,273	4,641	104.2	

*Estimated standing crop is within 5% of the actual standing crop

**Estimated standing crop is within 10% of the actual standing crop

IX. FIGURES

Figure 1. Estimated vs. actual standing crop (kg/ha) for fish of all sizes at 30 C. Biomass was estimated by dividing the quantity of feed provided by the actual % body weight consumed as determined from the dissections. The biomass was then expressed as a standing crop (kg/ha). This estimated standing crop was then compared to the actual standing crop of the pond from the day of harvest by linear regression.

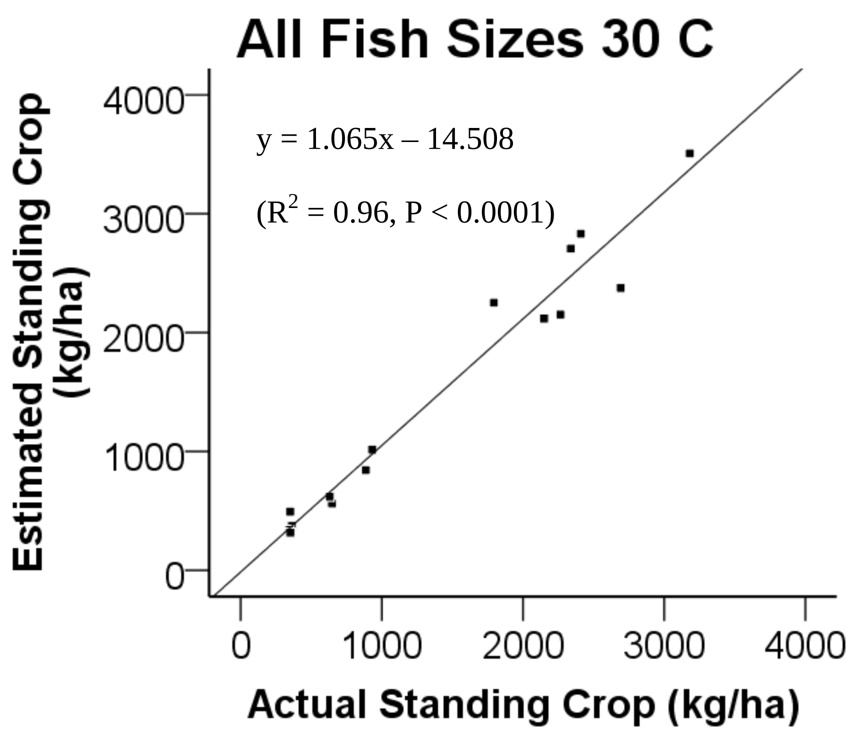
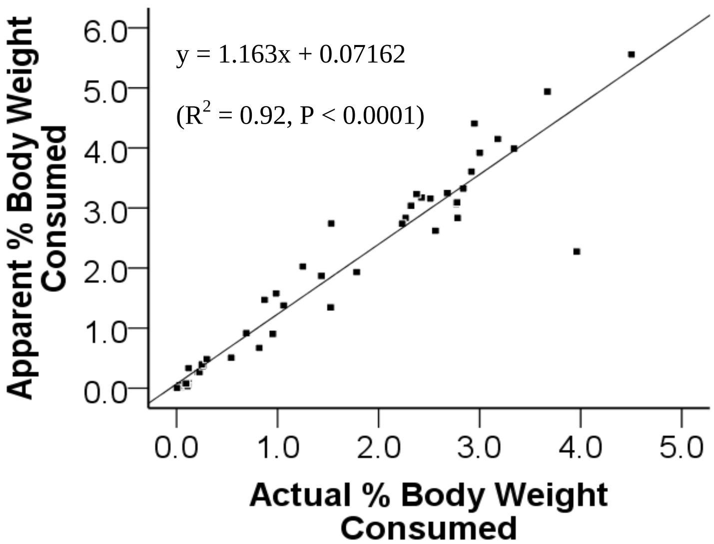


Figure 2. Apparent (uncorrected) and corrected apparent feed consumption vs. actual feed consumption for fish of all sizes and temperatures. Actual % body weight consumed was based on the fish dissections from the 25 fish sample for each pond. Apparent % body weight consumed (uncorrected) was based on the pond biomass and made the assumption that all of the feed was consumed, when fish were fed to satiation. Corrected apparent % body weight consumed was also based on the pond biomass, but assumed that only the percent of feed that floated was consumed.



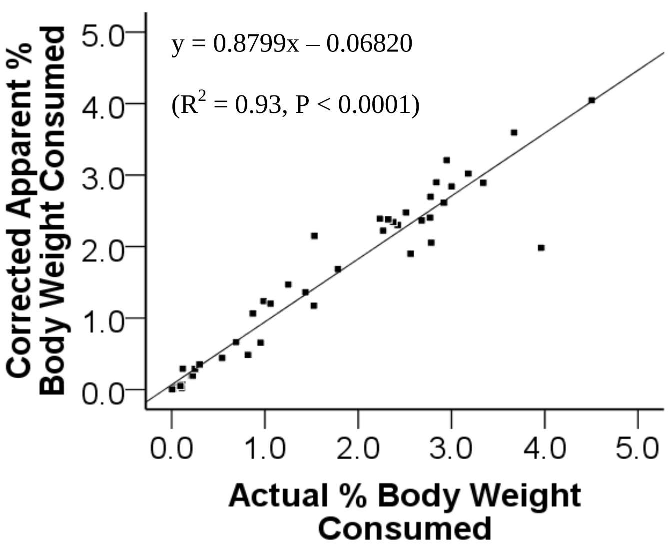


Figure 3. Magnitude of change in mean feed consumption (% body weight) by each size class as a function of temperature (% change using 25 C as a standard).

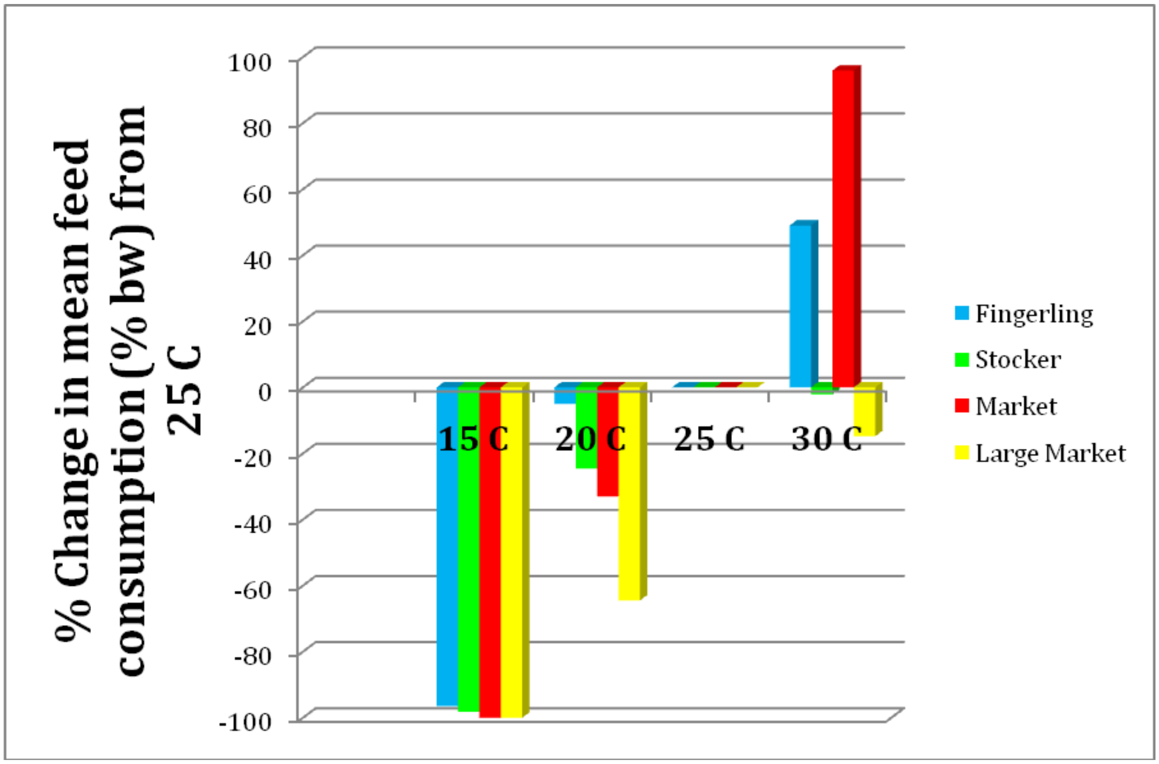


Figure 4. Percentage of non-feeding fish for each size class independent of temperature from the sample of dissected fish. Non-feeding fish were classified as fish that consumed less than 0.25% body weight.

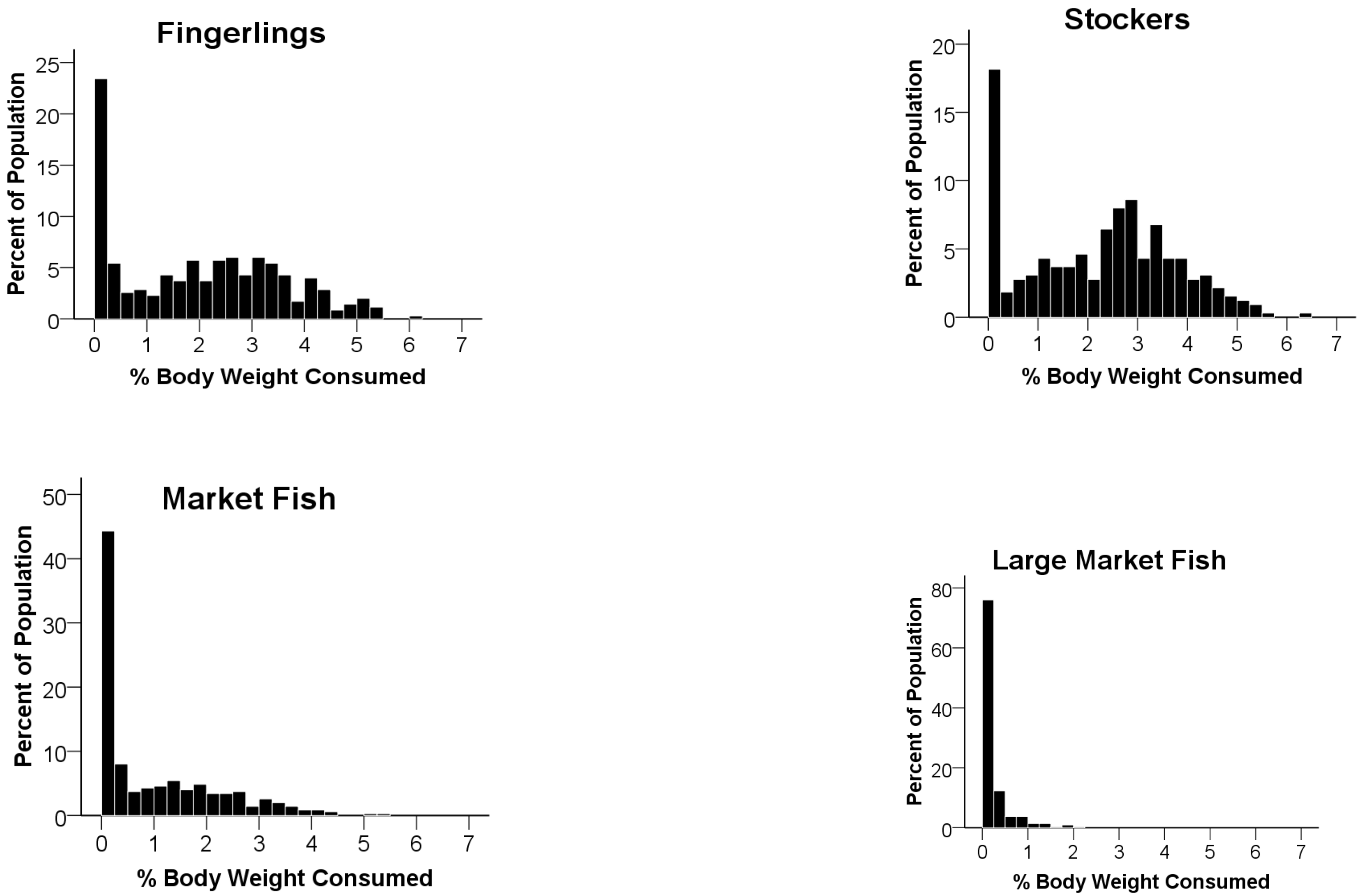


Figure 5. Percentage of non-feeding fish for each temperature independent of size class from the sample of dissected fish. Non-feeding fish were classified as fish that consumed less than 0.25% body weight.

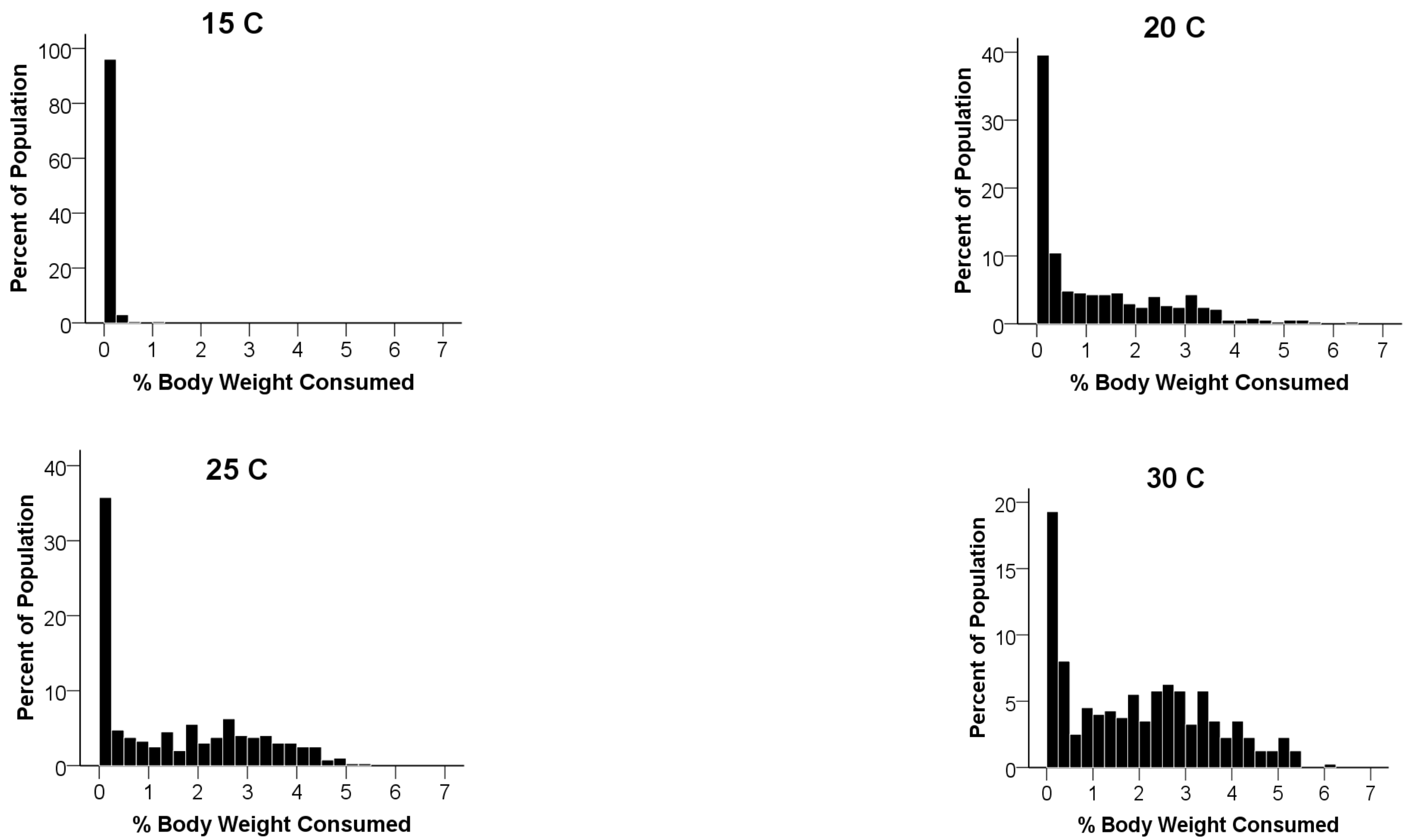


Figure 6. Feed consumption among individual fingerlings, stockers, market, and larger market fish at 15 C. The percentage of non-feeding fish represents fish that consumed less than 0.25% body weight.

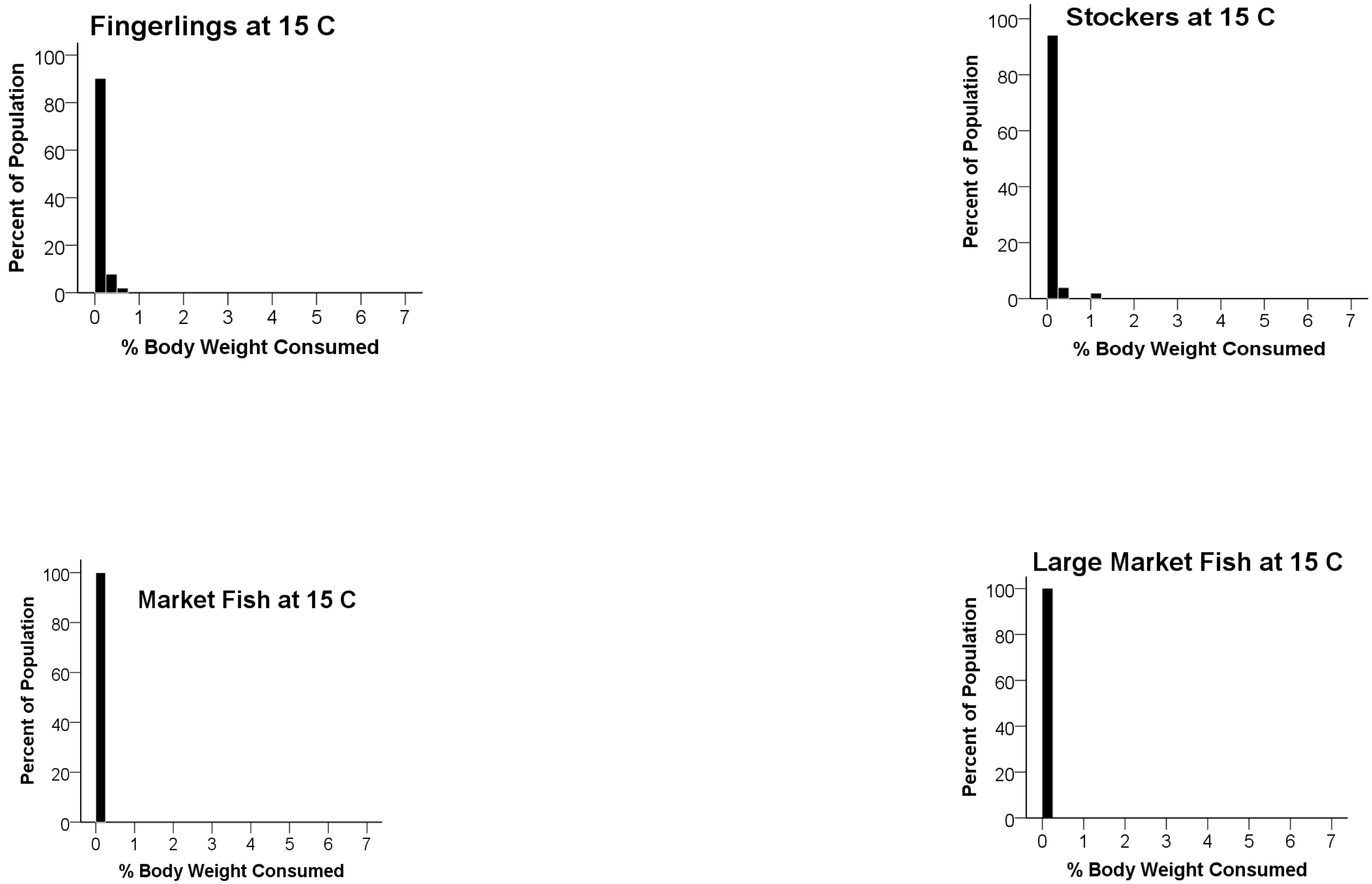


Figure 7. Feed consumption among individual fingerlings, stockers, market, and larger market fish at 20 C. The percentage of non-feeding fish represents fish that consumed less than 0.25% body weight.

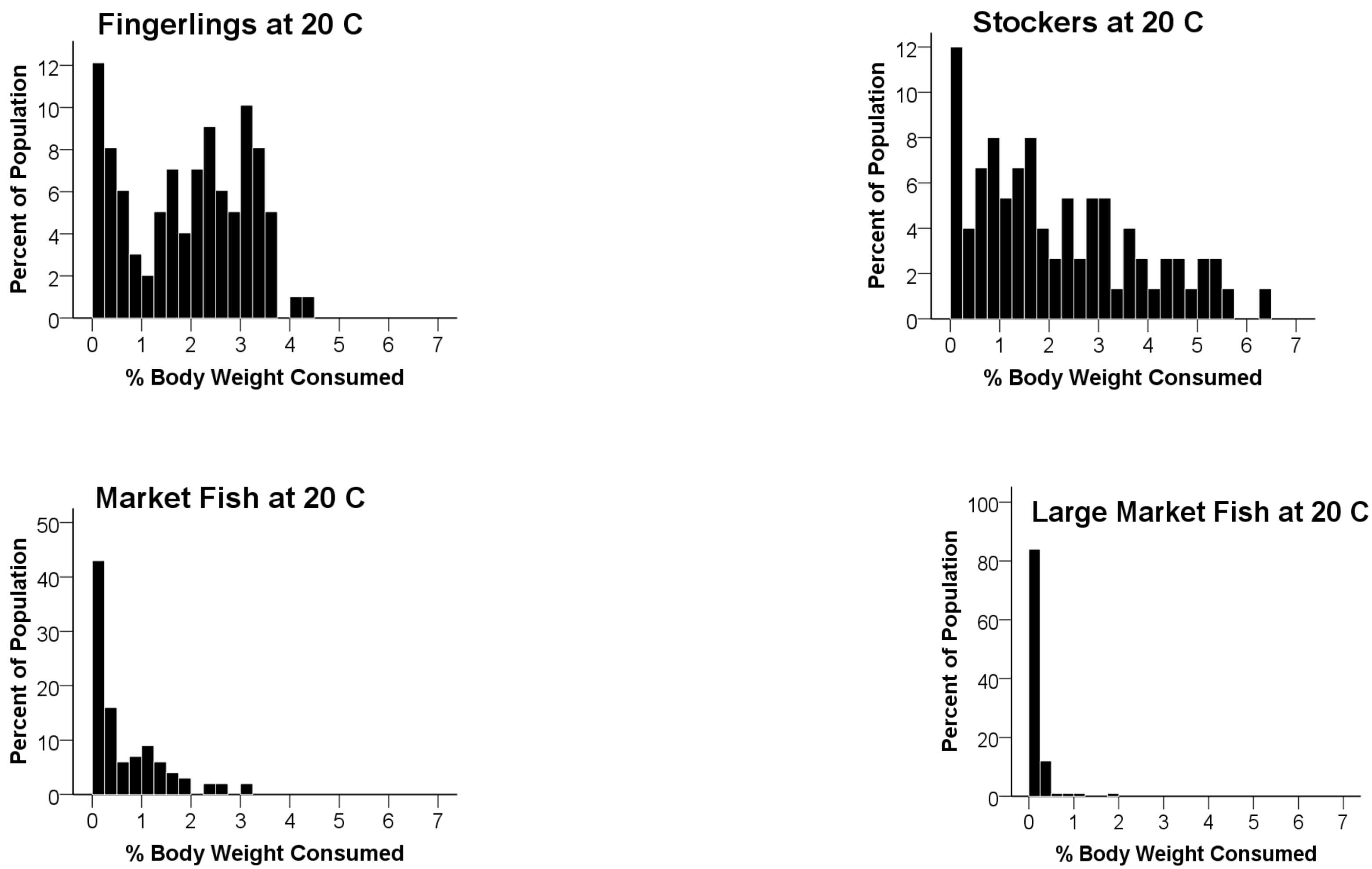


Figure 8. Feed consumption among individual fingerlings, stockers, market, and larger market fish at 25 C. The percentage of non-feeding fish represents fish that consumed less than 0.25% body weight.

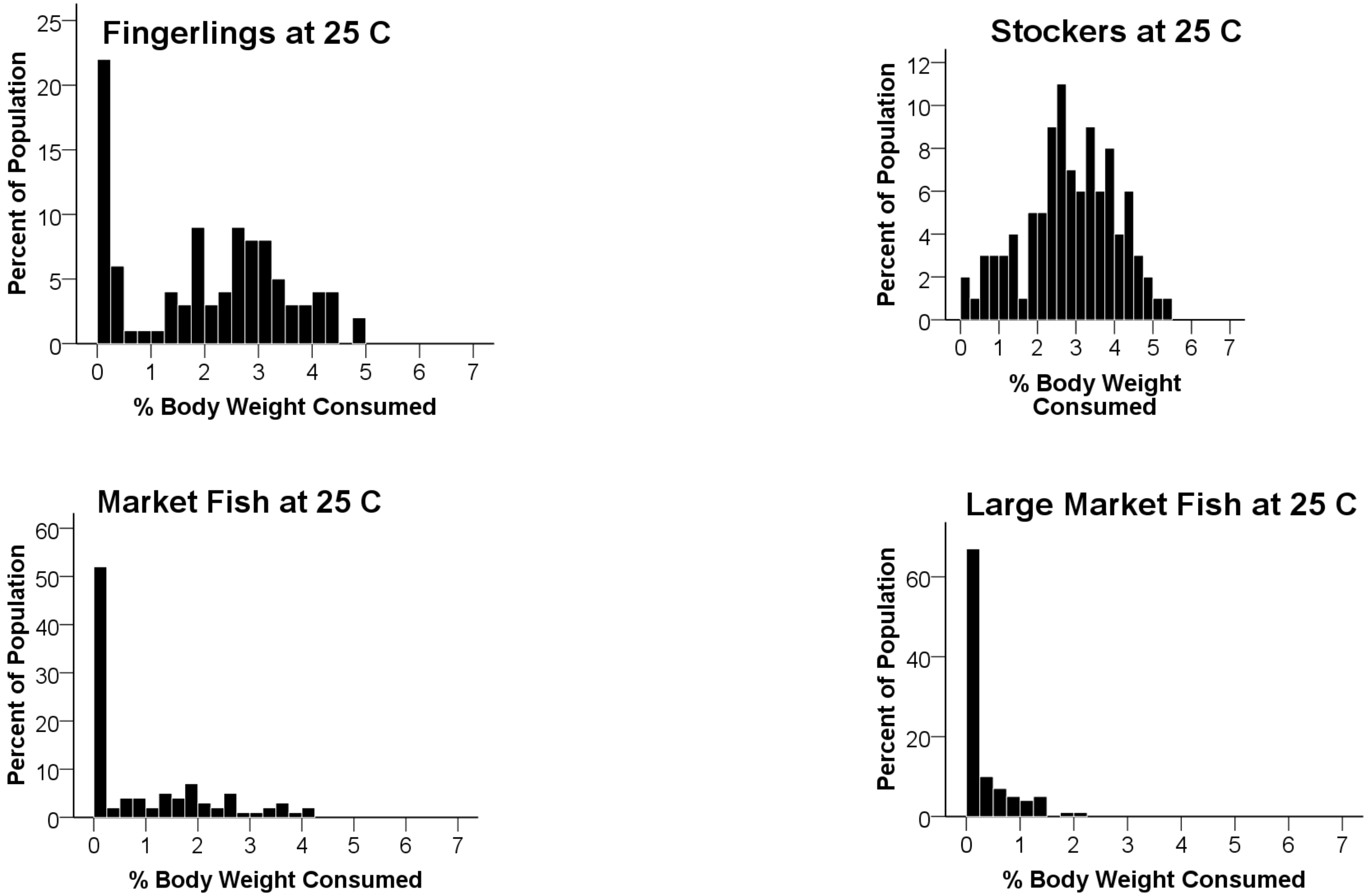
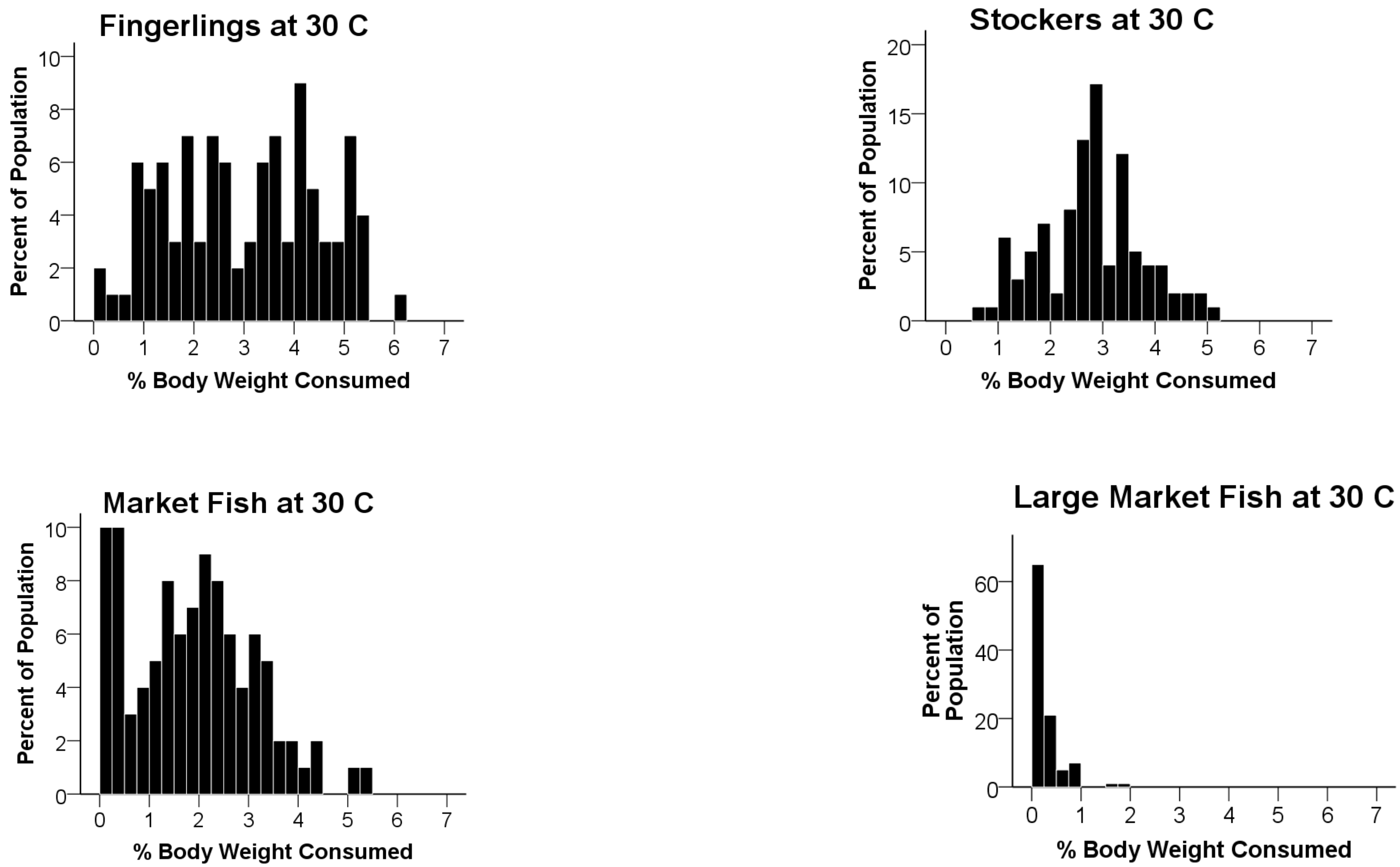


Figure 9. Feed consumption among individual fingerlings, stockers, market, and larger market fish at 30 C. The percentage of non-feeding fish represents fish that consumed less than 0.25% body weight.



X. APPENDICES

Appendix 1. Mean fish feed consumption among individual replicate ponds

Date	Pond	Size	Temperature	Actual %BW
4/15/10	E3	Large	20 C	0.21
10/11/10	E26	Large	20 C	0.01
10/14/10	E4	Large	20 C	0.01
5/13/10	E3	Large	25 C	0.87
5/14/10	E5	Large	25 C	0.23
10/25/10	E6	Large	25 C	0.01
10/28/10	E29	Large	25 C	0.11
6/24/10	E5	Large	30 C	0.26
8/31/10	E6	Large	30 C	0.25
9/3/10	E3	Large	30 C	0.30
11/15/10	E1	Large	15 C	0.00
11/17/10	E2	Large	15 C	0.00
4/14/10	E1	Stocker	20 C	0.95
10/10/10	E8	Stocker	20 C	3.96
10/12/10	E9	Stocker	20 C	1.52
5/10/10	E1	Stocker	25 C	3.00
5/14/10	E26	Stocker	25 C	2.78
10/26/10	E26	Stocker	25 C	2.78
10/27/10	E2	Stocker	25 C	2.84
6/22/10	E29	Stocker	30 C	2.77
6/25/10	E8	Stocker	30 C	2.27
8/31/10	E9	Stocker	30 C	3.18
9/1/10	E8	Stocker	30 C	2.95
11/17/10	E8	Stocker	15 C	0.00
11/18/10	E6	Stocker	15 C	0.09
4/12/10	E6	Market	20 C	0.69
4/13/10	E25	Market	20 C	0.82
10/9/10	E2	Market	20 C	0.02
10/14/10	E1	Market	20 C	1.06
5/12/10	E2	Market	25 C	2.56
5/13/10	E6	Market	25 C	1.25
10/25/10	E3	Market	25 C	0.00
10/28/10	E7	Market	25 C	0.05
6/24/10	E25	Market	30 C	2.51
6/25/10	E10	Market	30 C	0.99
9/2/10	E25	Market	30 C	1.43
9/3/10	E10	Market	30 C	2.68
11/15/10	E9	Market	15 C	0.00
11/19/10	E5	Market	15 C	0.00
4/12/10	E7	Fingerling	20 C	2.42
4/15/10	E4	Fingerling	20 C	2.92
10/9/10	E5	Fingerling	20 C	0.54
10/10/10	E6	Fingerling	20 C	1.78
5/12/10	E28	Fingerling	25 C	2.38
5/10/10	E9	Fingerling	25 C	3.34
10/26/10	E8	Fingerling	25 C	0.12
10/27/10	E5	Fingerling	25 C	2.23
6/21/10	E4	Fingerling	30 C	2.32
6/22/10	E9	Fingerling	30 C	1.53
9/1/10	E5	Fingerling	30 C	3.67
9/2/10	E29	Fingerling	30 C	4.50
11/16/10	E26	Fingerling	15 C	0.11
11/18/10	E3	Fingerling	15 C	0.03